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In This Issue

Composition Roll Neck Bearings—by H. R. Gilchrist, Lubrication Engineer, Carnegie-Illinois Steel Corporation, Youngstown, Ohio 19

Discussion: Composition Roll Neck Bearings—Presented by C. R. Hand, W. A. Rankin, K. T. McGill, H. R. Gilchrist, K. W. Atwater, C. P. Irvin and H. C. Irvin 25

Factors of Open Hearth Design and Practice—by W. C. Buell, Jr., Steel Plant Consultant, Arthur G. McKee and Company, Cleveland, Ohio 28

Discussion: Factors of Open Hearth Design and Practice—Presented by G. M. Coughlin, H. T. Watts, F. E. Leahy, W. P. Albaugh, R. I. Gumaer, C. E. Hague and W. C. Buell, Jr. ... 35

Development in Forging Practice—by John L. Young and J. J. Andra, United Engineering and Foundry Company, Pittsburgh, Pennsylvania 41

Discussion: Development in Forging Practice—Presented by J. A. Succop, W. J. Pattison, M. Fournier, C. F. Seyler, Stevenson Findlater, C. C. Levy, J. L. Young, A. D. Dauch, C. H. Hunt and J. L. Cox 48

Power Consumption of Hot Strip Mills—by W. M. Ballenger, Engineering Department, General Electric Company, Chicago, Illinois, and T. R. Rhea, Industrial Department, General Electric Company, Schenectady, New York 54

Discussion: Power Consumption of Hot Strip Mills—Presented by A. F. Kenyon, F. D. Egan, A. R. Dibben, W. M. Ballenger and G. E. Stoltz 62

Effects of Storage and Oxidation of Coal Upon Coking Properties—by L. D. Schmidt, Associate Chemist, Central Experiment Station, Bureau of Mines, United States Department of Interior, Pittsburgh, Pennsylvania 64

Discussion: Effects of Storage and Oxidation of Coal Upon Coking Properties—Presented by D. P. Finney, F. A. Hagedorn and J. D. Price 70

Latest Design and Equipment for the Industry 74

Annual Spring Conference, Association of Iron and Steel Engineers—Tentative Program 83

Items of Interest 84

A.I.S.E. District Section Activities 85

Index to Advertisers 14

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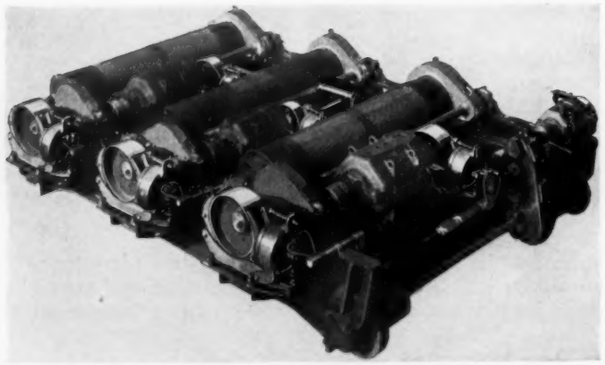

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For BRAKING at Top Efficiency — use EC&M Type WB BRAKES

Composition Roll Neck Bearings

By H. R. GILCHRIST, *Lubrication Engineer*
CARNEGIE-ILLINOIS STEEL CORPORATION
YOUNGSTOWN, OHIO

Presented before A. I. S. E. ANNUAL CONVENTION, CHICAGO, ILLINOIS, SEPTEMBER 24-27, 1940

▲ UNTIL a few years ago the conventional bronze, babbitt, or bronze-babbitt bearings for rolling mills, with their lubricant packed against the roll neck in the form of heavy grease, had been used for so many years in the steel industry that they were becoming almost the universally accepted practice.

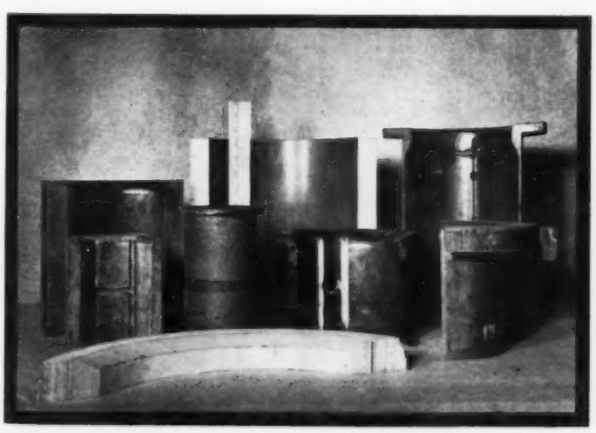
The great waste in grease lubrication is the failure of this grease to stay on the neck and lubricate properly, with consequently high frictional losses. The short life of the bearing itself, accompanied by roll neck scoring and the difficulty of holding gauge tolerances, have all strongly focused attention on the bearing problem. One of the most important results of the study of this problem has been the development and successful application of composition bearings to roll necks; the characteristics of the bearings are such as to almost entirely eliminate the objections found in the use of the old metal bearings. Water, which is always present in the steel mill, is the ideal lubricant for them.

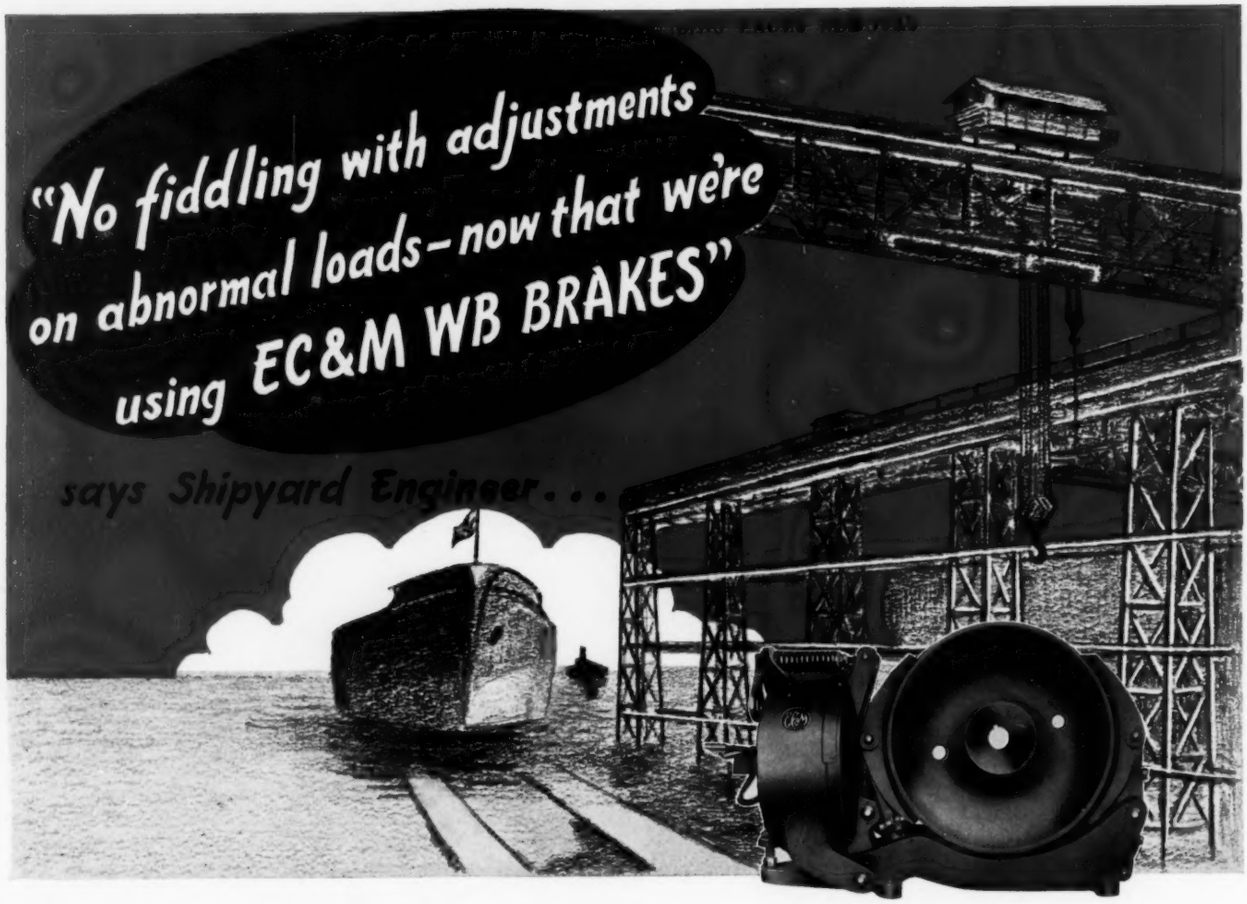
Figure 1 shows some of the various shapes of bearings used; the two piece roll neck bearing with separate radial shell and thrust collar, the block type roll neck bearing, pinion, crane, and vertical edger bearings, all of which are giving good results with long life.

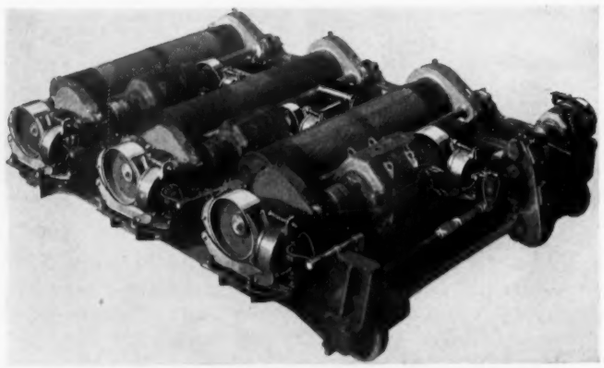
Good roll necks are of the utmost importance for the successful use of composition bearings. Figure 2 shows a roll neck that was used with a bronze bearing and poorly lubricated, and is typical of necks used under these conditions. To use a neck like this with a composition bearing would allow the edges of the cracks to act like a series of knives that would soon cut through the bearing. A roll neck like this can be ground so it will work satisfactorily, but the cracks cannot be

Figure 1—Below

Figure 2—Right







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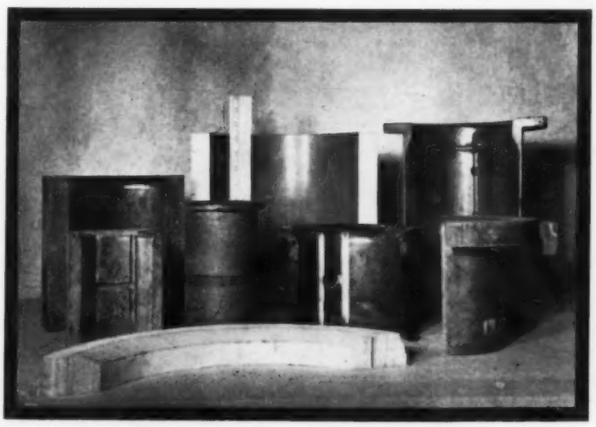


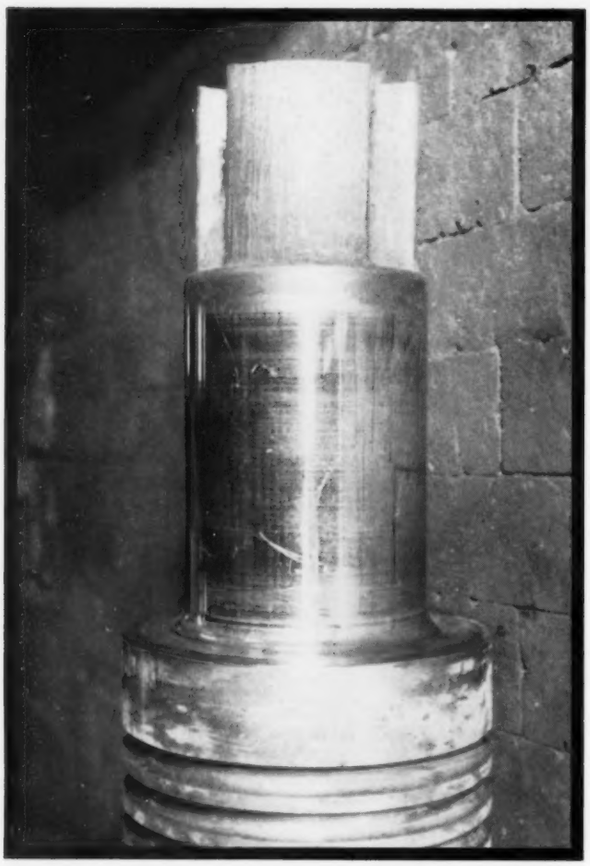


Figure 3

removed completely. For best results, necks should be ground after they are turned in the lathe, but a smooth turned neck will work. Figure 3 shows a neck that has been used with composition bearings; the few marks on it are merely on the surface, and were probably caused when the roll was removed from the housing.

With the arrangements generally used in two-high mills, the bottom roll rests on the bearings with nothing to hold it down but its own weight. This is usually satisfactory with bronze bearings. With composition bearings, however, the friction is so little with the pass running empty that the bottom roll runs so free the coupling boxes rattle. Occasionally when a bar enters the pass the bottom roll will slow down or stop momentarily until the lost motion in the couplings is taken up; this turns the end of the bar down enough to cause a sticker or a cobble in the next pass. At times the roll will jump out of the bearings allowing scale and dirt to get under it, which scores the neck, thus greatly shortening the life of the bearings. Figure 4 shows one way of overcoming these difficulties by making a hold-down, or separator, which holds the top and bottom rolls in place. With this type of hold-down the hanger bolts which were formerly used are removed, and rods put in which fit into sockets in the bolts to spread the plates apart. It can be seen that the plates are not kept level in practice, and they are often bent from being tightened too much.

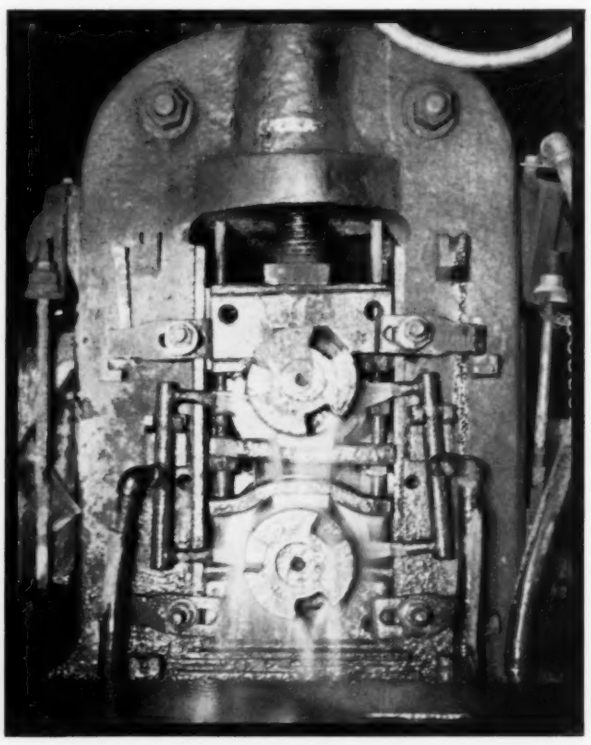
Figure 5 shows a more satisfactory type of hold-down, as the rolls are more easily lined up and held in the proper positions by adjusting the wedges. This type is more expensive, however, as it requires the drilling of the housing for the bolts.

Composition bearings require enough water to keep the neck cool, but it need not be supplied at a very high pressure. Figure 4 shows one method of applying the water in which a flattened pipe is used on either side of each roll neck. With this arrangement the water washes along the side of the bearing and helps to carry out scale and dirt. In some cases the pipes are not flattened, but are merely cut off to the required length. Figure 5 shows another type of water pipe which runs the length of the neck with small holes drilled in it an inch or so apart. Water applied in this way has almost no ability to wash scale and dirt out of the bearing, and these holes are easily clogged. The usual river water used in steel mills is likely to contain sand, small sticks, leaves, fish and other debris, unless it is filtered. This type of pipe is more suitable for long necks than an open end pipe.

When the water in use contains more than 10 parts per million acid, an alkali should be added to neutralize it. The acid has no effect on the bearing itself, but it pits the necks, making them rough. This causes the bearing to wear rapidly. The chart shown in Figure 6 is a guide for the pump house operators in liming the water. Samples of water should normally be tested every four hours, and if the acid content is fluctuating rapidly, they should be tested as often as necessary to maintain the proper lime feed.

Figure 7 shows a method of getting more life out of worn bearings. The bearing on the left is new; the center one has had a great amount of end thrust in the mill,

Figure 4



LIME TREATMENT OF SERVICE WATER

BASED ON 25,000,000 GALS PUMPED PER 24 HRS

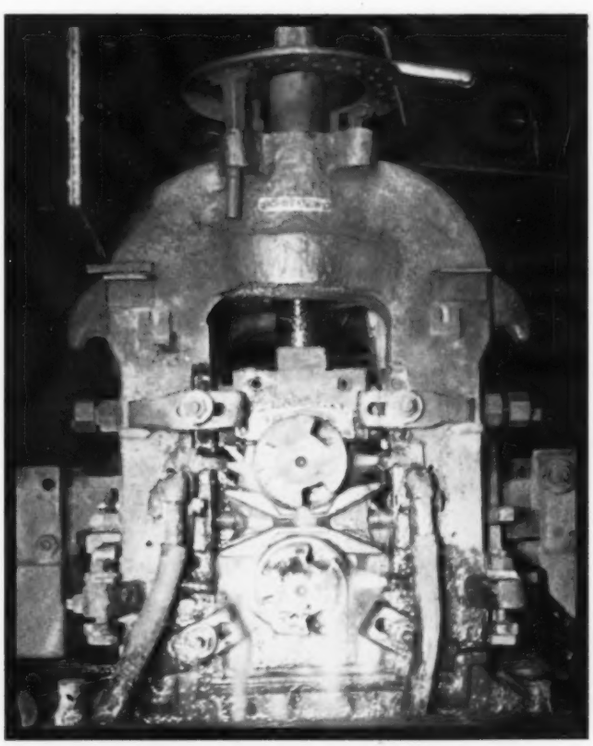
Parts Per Million Acid	Grains Per Gallon Lime	P.P.M. Acid	Lime	P.P.M. Acid	Lime	P.P.M. Acid	Lime	P.P.M. Acid	Lime	P.P.M. Acid	Lime	P.P.M. Acid	Lime
1	0.14	21	48	41	88	91	133	121	178	151	218	181	264
2	0.29	22	46	42	90	92	134	122	176	152	219	182	265
3	0.43	23	46	43	91	93	134	123	177	153	221	183	266
4	0.58	24	49	44	92	94	136	124	179	154	223	184	267
5	0.72	25	51	45	94	95	137	125	180	155	224	185	267
6	0.87	26	53	46	96	96	139	126	182	156	225	186	268
7	1.01	27	54	47	97	97	140	127	183	157	226	187	270
8	1.16	28	57	48	98	98	142	128	184	158	228	188	271
9	1.30	29	58	49	100	99	143	129	186	159	229	189	272
10	1.45	30	59	50	101	100	145	130	188	160	231	190	274
11	1.6	31	59	51	102	101	146	131	189	161	232	191	275
12	1.7	32	61	52	103	102	147	132	190	162	234	192	277
13	1.9	33	62	53	105	103	149	133	192	163	235	193	278
14	2.0	34	64	54	106	104	150	134	193	164	237	194	280
15	2.3	35	65	55	108	105	151	135	195	165	238	195	281
16	2.3	36	67	56	110	106	153	136	196	166	239	196	283
17	2.5	37	68	57	111	107	154	137	198	167	241	197	284
18	2.6	38	69	58	112	108	156	138	199	168	242	198	286
19	2.7	39	71	59	114	109	157	139	201	169	244	199	287
20	2.9	40	73	60	115	110	158	140	202	170	245	200	288
21	3.0	41	74	61	117	111	160	141	203	171	247	201	290
22	3.1	42	76	62	118	112	161	142	205	172	248	202	291
23	3.3	43	76	63	120	113	163	143	206	173	249	203	293
24	3.5	44	79	64	121	114	164	144	208	174	251	204	294
25	3.6	45	79	65	123	115	166	145	209	175	252	205	296
26	3.8	46	81	66	123	116	167	146	211	176	254	206	297
27	3.9	47	82	67	124	117	169	147	212	177	255	207	299
28	4.1	48	84	68	126	118	170	148	214	178	257	208	300
29	4.2	49	85	69	127	119	172	149	215	179	258	209	301
30	4.3	50	87	70	129	120	173	150	217	180	260	210	303

Figure 6

but still has considerable life in the body. To prolong the life of a bearing in this condition, an old bearing is cut into pieces about two inches wide, as shown on the right, and these are put into the carriage behind the worn bearing.

Figure 8 is a typical two piece bearing, showing the way it is mounted. The thrust collar is cut down lower than the shell, making it easier to apply a new collar to a worn shell; this also furnishes a groove to carry

Figure 5



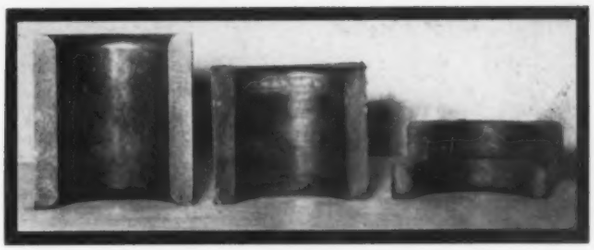


Figure 7

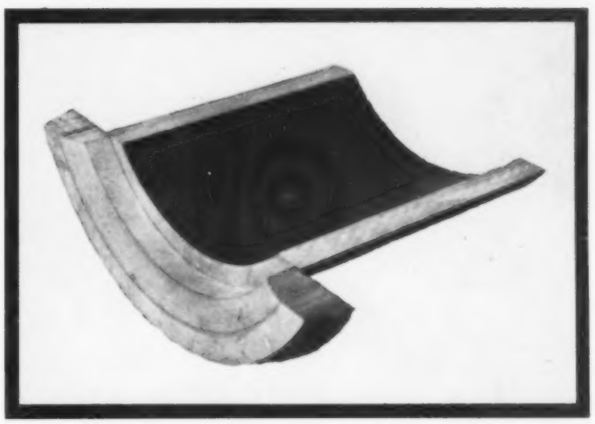


Figure 8

Figure 9

water into the fillet of the roll, providing better cooling. It should also be noticed that the shells are not chamfered, as this would hold small pieces of scale and other foreign matter which would roughen the neck and shorten the life of the bearing.

It is important to keep scale out of the bearings. Figure 9 shows a scale guard which is giving very good results on roughing stands. It is merely a flat plate with old composition or wood collars which fit against the bodies of the rolls at the fillets. While this is by no

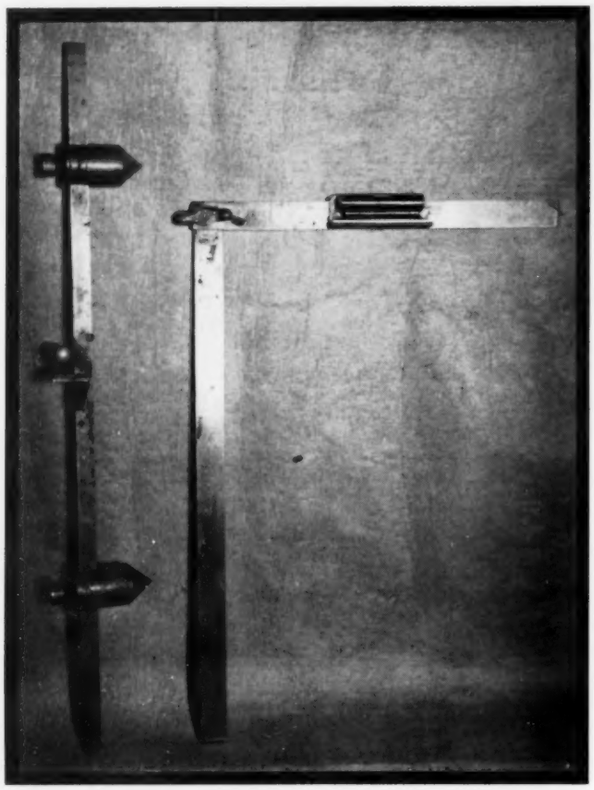


Figure 10

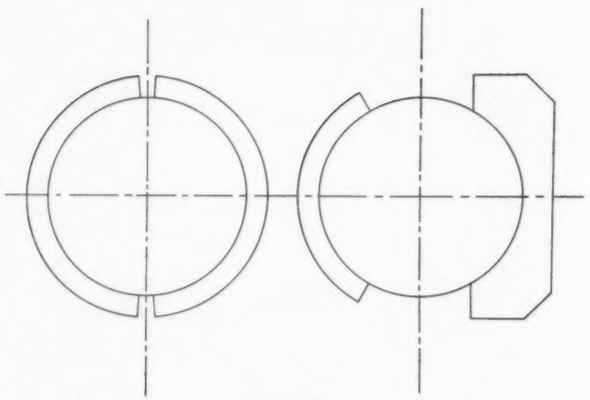
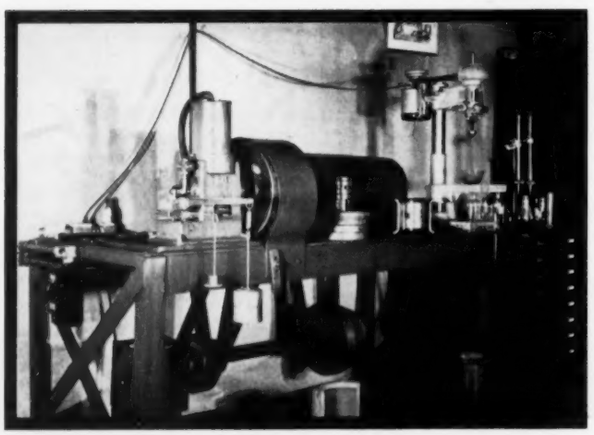


Figure 11

Figure 12



means perfect, it will keep out most of the scale and is easy to handle.

After making a new installation of composition bearings, all sorts of troubles, both real and imaginary, are blamed on the bearings. One thing that frequently happens that prevents the roller from getting a good bar is crossed rolls. To check the roll alignment, instruments were developed to use for setting up the rolls, as shown in Figure 10. The one on the left is a square bar carrying a level, mounted perpendicular to it and two movable points to fit the centers of the rolls. This is applied to both ends of the rolls in the housing, and when both ends are vertically over one another, as indicated by the level, the rolls must be parallel. The other is simply two flat bars hinged together at the ends, with a level parallel to one of them. To use this, the operator holds the plain bar against the faces of the rolls near their ends and adjusts the other bar until it is level. He then tightens the wing nut and moves to the other end of the rolls. If they are parallel, the one bar will still be level. The latter type instrument is the only one which can be used when it is impossible to get to both ends of the rolls.

For the first few years that composition bearings were used, it was said that they would not work satisfactorily at low rubbing speeds. However, a 10 in. continuous bar mill which is completely equipped with composition bearings operates at speeds as follows:

Stand	Type	Rubbing speed of roll necks, ft. per min.
1	2-high	28–114
2	2-high	38–134
3	2-high	57–201
4	2-high	89–286
5	2-high	133–428
6	2-high	180–632
7	2-high	216–660
8	2-high	286–706
9	Vertical edger	339–870
10	2-high	467–1120
11	Vertical edger	495–1230
12	2-high	696–1400

The speeds shown are the extreme range possible in the various stands, but the actual speeds encountered will never quite reach these limits.

The parts that make up a bearing for strip mill roughing stands are a radial shell, four plugs which hold the neck of the roll down, a seal ring, and a thrust collar. The thrust load on these bearings is not taken at the fillet of the roll, as is the usual practice, but is taken on an extra shoulder at the outer end of the neck. Some of these bearings have been in service for more than four years and are still going. This goes to show that a fully enclosed bearing that can retain the water and keep out scale will last longer. Tests show that if composition bearings are put on a circulating system, using an emulsion containing about 90 per cent water, bearings should last indefinitely.

Trouble has been experienced with shell type bearings on vertical edger rolls that almost completely surround the neck. These had water applied at the edges of the bearings and through water grooves in their centers, but they always ran somewhat hot. Bearings

made in this way, as shown on the left in Figure 11, have a tendency to squeeze in at the edges adding further to the heat. To overcome this, the bearings were cut down to 120 degrees of contact and to a block type where possible, as shown on the right. This strengthens the bearing and allows more of the roll neck to be exposed to the water. The part which remains a shell is merely a carrier; there was not room enough in actual service to change it to a block type.

It has always been a serious question with all users of composition bearings as to which makes of bearings are best suited to the various kinds of service. A method has been developed for running wear tests in the Timken lubricant tester, in which the steel test blocks are replaced with blocks of the material to be tested the same size as the steel blocks. Water is applied to the bearing instead of circulating oil.

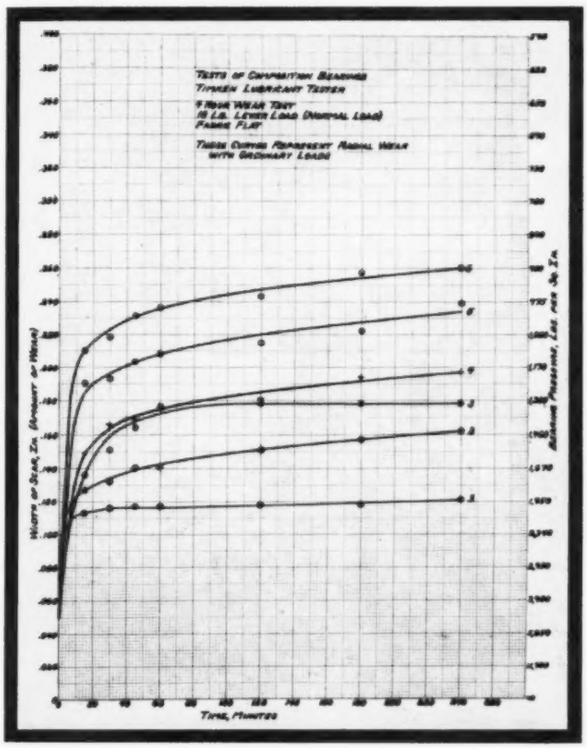


Figure 13

Tests are made for definite periods of time, with one load about the same as is generally encountered with roll neck bearings, and one five times as great. These two loads are applied to the flat face of the fabric and then to its edge. The width of the scar on the test block is measured at intervals as an indication of the amount of wear, and the results are then plotted with those of other materials tested under the same conditions.

In making tests in this way, the many troubles encountered in steel mill operations, such as clogged water lines, too much tightening of bearings, etc., are eliminated, and most conditions affecting bearing life can be controlled. It is true that these tests measure only wear and do not take into account other factors which affect bearing life, especially shock loads.

Figure 12 is a general view of the tester, which is driven through a series of cone pulleys by means of which the speed can be adjusted over a wide range. Notice the lever arm carrying the weights with which

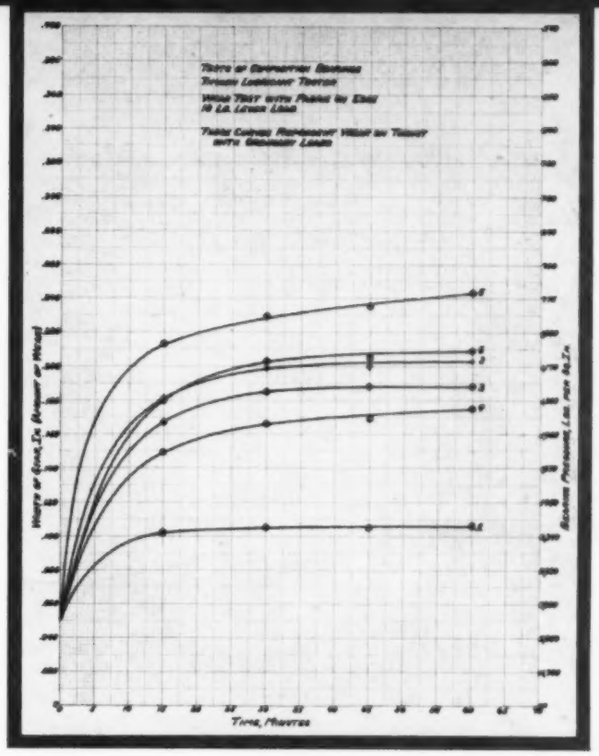

Tests of Composition Bearings
Timken Lubricant Tester
Wear Test with Fabric on Edge
18 Lb. Lever Load
These Curves Represent Wear on Thrust
with Ordinary Loads
Time, Minutes

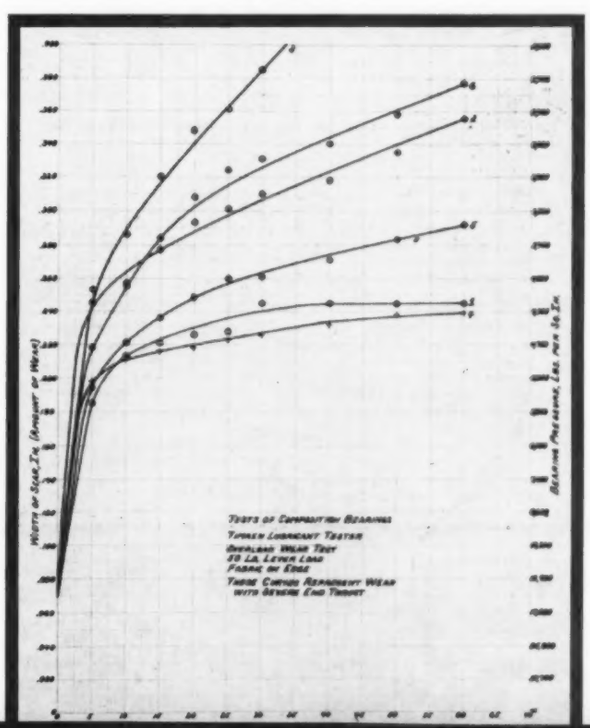
Figure 14

the bearing is loaded, and the friction arm below it to measure the coefficient of friction. The lever arm arrangement is carried on knife edges to secure perfect alignment.

Figure 13 is a set of typical curves of six different bearing materials with normal loads representing ordinary radial wear. The material numbered 1 is the best under these conditions, as it wore the least; the others are numbered according to their rates of wear. Figure 14 shows the same materials with the same load, but with the load on the edge of the fabric instead of on the flat face of it. This is indicative of the wear on a bearing in the direction of the end thrust with block type bearings (not those with separate thrust collars). It will be seen that No. 1 material is also the best under these conditions, but that No. 4 is second, with the others wearing more.

Figure 15 shows the performance of these materials with five times as much load on the face of the fabric.

Figure 15



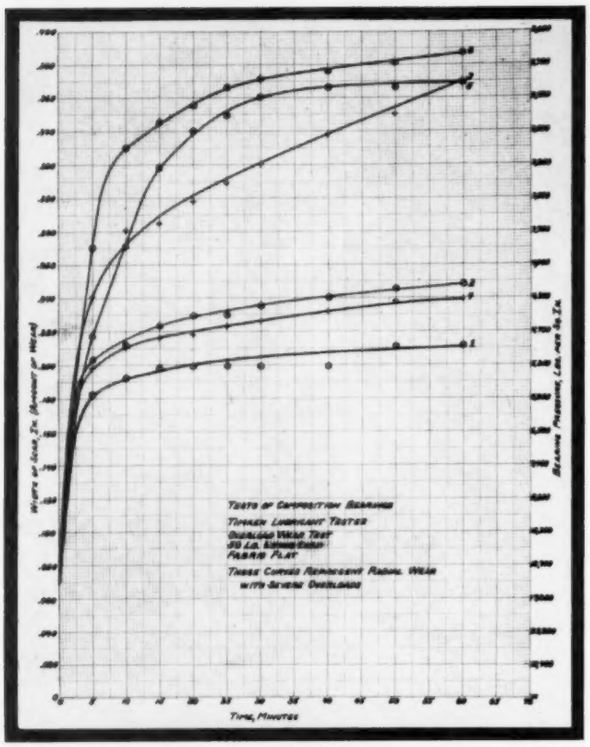
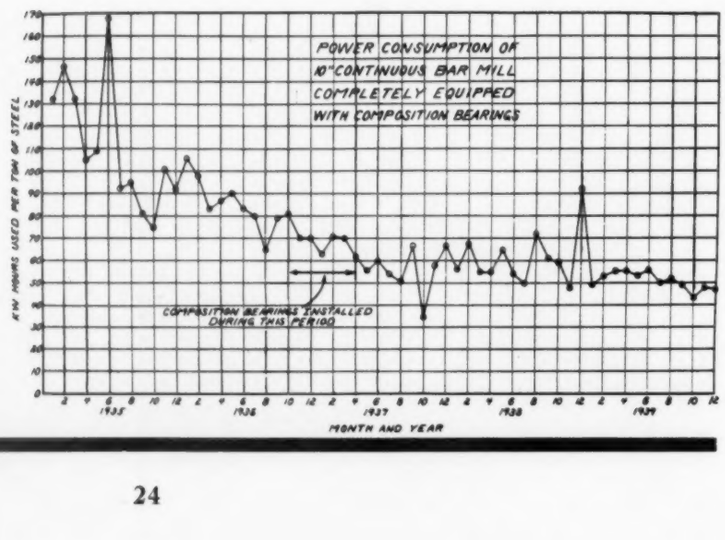


Figure 16

Figure 17

Here Nos. 1, 4, and 2, are all close together, with the other three wearing considerably more. Figure 16 is with the higher load on the edge of the fabric. Under these conditions No. 1 is not quite as good as No. 4, with the others showing more wear.

Figure 18



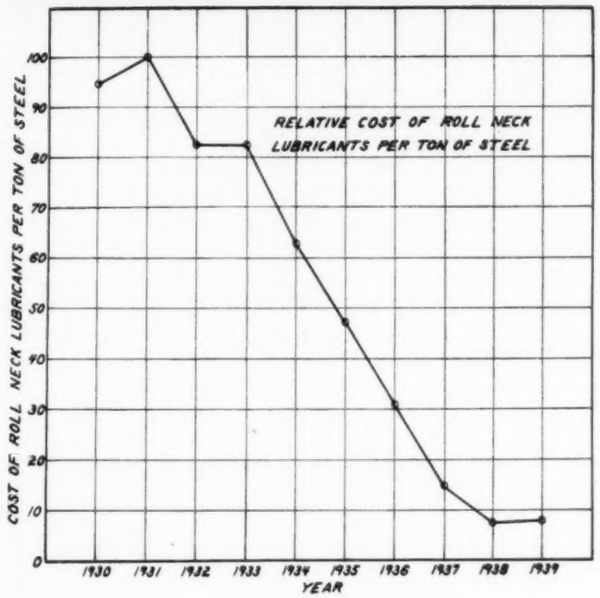
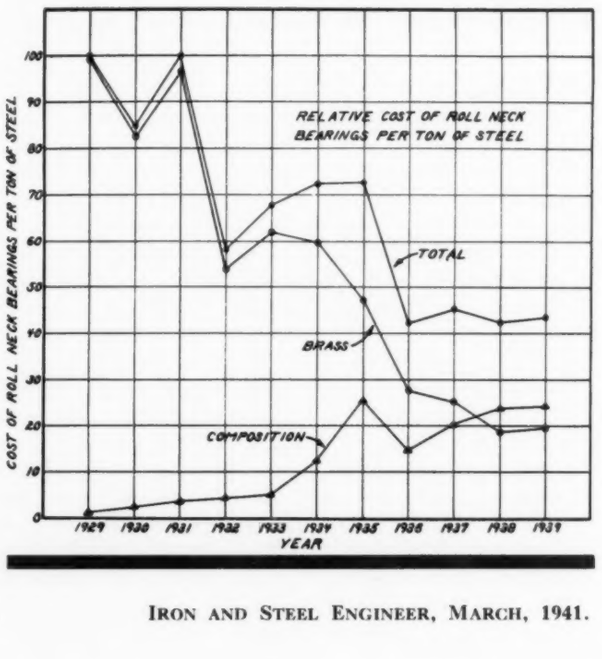


Figure 19

These curves show that the load conditions must be taken into account for a particular application. Some bearings will not stand end thrust, while others cannot take severe overloads.

There has been considerable discussion as to whether or not water actually lubricates composition bearings by maintaining a fluid film between the neck and the bearing, or merely keeps it cool. A bearing was placed in the tester with the normal load on the flat fabric, and the space between the shaft and the guard packed with dry ice. This ran all right for about ten minutes,

Figure 20



when the bearing began to burn. The shaft remained quite cool, since it was in contact with the dry ice. The wear during this time was about twice as great as it would have been with water. This shows that to a certain extent water does act as a lubricant, but permits considerable metal to bearing contact.

Another use for this material, somewhat different than roll neck bearings, is slipper plates for universal couplings. When brass slippers become worn they are noisy, and it was principally to get quieter operation that it has been attempted to use composition material in this service. Composition slippers do give quiet operation and do not wear nearly as fast as brass; however, they all seem to break as shown in Figure 17. This is in no way the fault of this particular material, but is typical of all composition slippers. To my knowledge they are not successful as yet, but they are being kept in service in an attempt to overcome the difficulties encountered with their use.

It is well known that composition bearings have a lower coefficient of friction than bronze bearings. Figure 18 shows the power consumption of a mill completely equipped with composition bearings before, during, and after their installation. The drop during the first year shown on the curve was due to the installation of automatic greasing equipment on the bronze roll neck bearings. However, it can be seen that a further reduction in power was accomplished by the use of composition, as well as savings in bearing and grease costs.

Figure 19 shows what has happened to the cost of lubricating roll necks during the time composition bearings were being installed to replace bronze and babbitt bearings. In 1939, the cost per ton was less than one-tenth of what it was at its highest.

Figure 20 shows the relative cost of roll neck bearings per ton of steel from the time composition bearings were first installed. As the use of composition bearings has been increased, the total cost of roll neck bearings has been reduced, so that at present it is less than half what it once was.

DISCUSSION

PRESENTED BY

C. R. HAND, *Lubricating Engineer*, Bethlehem Steel Company, Sparrows Point, Maryland.

W. A. RANKIN, Engineering Division, Bearings and Gears, Gatke Corporation, Chicago, Illinois.

K. T. McGILL, *Manager*, Ryertex Division, Joseph T. Ryerson and Son, Inc., Chicago, Illinois.

H. R. GILCHRIST, *Lubrication Engineer*, Carnegie-Illinois Steel Corporation, Youngstown, Ohio.

K. W. ATWATER, *Consulting Industrial Engineer*, Pittsburgh, Pennsylvania.

C. P. IRVIN, *Micarta Headquarters Representative*, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pennsylvania.

H. C. IRVIN, American Brakeblok Division, American Brake Shoe and Foundry Company, Pittsburgh, Pennsylvania.

C. R. HAND: Mr. Gilchrist's paper has been very interesting, particularly so in that his experiences parallel our own. Too much stress cannot be put on the importance of good roll necks. However, just what standards a roll neck must meet, to roll on composition bearings, we are unable to state. Appearance is not always reliable. Some necks look excellent, yet run badly. Rough and cracked necks cannot be used. However, rolls having grooves running around the neck can be used. These are almost always the case after long runs, and result from particles of scale becoming embodied in the composition.

Application of water to composition bearings has been given much attention. Our experience shows that each mill must be studied and water applied as the individual bearings require. High pressure is never advantageous. Volume required varies with the speed and scale condition. All necks show the effects of acids in the cooling water. Some show very marked etching, others slight discolorations.

Many types of materials have been tried—canvas, paper or cotton beltings laminated, macerated moulded materials, lignum-vitae sawdust compounded with bakelite, and combinations of two or more ways of laying plys. Some manufacturers have tried various mineral additions, oxides of aluminum and magnesium, graphite and mica. Some superiority was claimed for each bearing. Our experience shows that while one type may serve well in one mill, it does not serve at all in others.

Manufacturers have cooperated without reserve in developing composition bearings. Operating departments have been patient. All of which has contributed to the successful use of what once was regarded as ridiculous material for rolling mill bearings. The results have been 30–40 per cent reduction in power with less off-gauge, safe and cleaner mills and almost entire elimination of grease and tallow from the mill sections.

W. A. RANKIN: I heard only part of Mr. Gilchrist's paper and have but little criticism to offer, yet would like to point out that while a few failures have occurred with fabric slipper bearings, I can assure you they are by no means in proportion to the failures that occur with metal bearings. On the vast majority of installations, fabric slippers have proved extremely successful, and today they are effecting incalculable economies on all types of rolling mills.

To accomplish this result, universal coupling operation was thoroughly analyzed for a complete understanding of the severe service to which slipper bearings are subjected. In our textile plants tough special fabrics were developed to give maximum resistance to breakage. Special moulds were perfected for moulding slippers to the finished size in order that the severe wear would be borne by the dense wear-resisting moulded surface. The tough fabrics were assembled in moulds so as to produce structures combining great shock-absorbing resilience with tremendous strength. Moulding processes were originated that apply correct pressure in the same direction pressures are applied to the slippers in service.

All these and countless other developments perfected over a period of years have produced entirely new qualities in slipper bearing performance. On large blooming mills, for example, where great shocks and frequent reversing makes slipper service most difficult, a set of fabric slippers are still in service after three years of continuous operation. On the same application the metal bearings originally used were giving but two or three months of service, with occasional failures in a few days' time. Hundreds of equally gratifying applications have been made covering just about every type of mill where universal couplings are used.

Of perhaps even greater advantage than the extended wear life is the fact that the use of fabric slipper bearings avoids wear and scoring of companion parts, eliminating the great maintenance expense. This is a factor of major importance, particularly today when demands on machine shops are so great.

Another advantage about which users have commented is the elimination of deafening noise, pounding, slapping and vibration.

Despite years of extensive development work and the marvelous achievements attained, the application of fabric slippers has remained rather critical. The few failures experienced have almost invariably been due to improper fitting.

When clearances are too small, expansion caused by temperature changes may result in loss of lubrication and short life of the slipper. Even in such cases, however, sockets and spades have not been damaged.

When clearances are too great, the free, or inactive ends of the slippers may follow the spade away from the socket, and when no longer completely engaged with the socket, the slipper may be broken by the spade in reversing or taking up the load, as outlined in Mr. Gilchrist's paper.

The recently developed self-aligning slipper bearings incorporate pressure springs which hold the slippers in complete engagement with the socket. The compression springs are seated in the slippers and bear against large circular discs, or buttons, which are fitted into the slipper and bear against the spade. Each spring exerts a pressure many times the weight of the slipper for which it is designed—sufficient pressure to hold the slipper in continuous, full-length engagement with the socket.

The self-aligning feature eliminates the need for critically accurate clearances and makes the application of slipper bearings practically fool-proof.

Pressure of the slippers against the socket sets up an excellent condition for effective lubrication. The grease, even at the inactive end of the slipper is held in and continuously spread. Heavy reversing loads, therefore, are borne by well-lubricated slipper and socket surfaces. Grease slinging and the undesirable conditions it creates are avoided.

Since the slipper is continuously engaged with the socket, there is no chance for breakage by reversing motion of the spade—the cause of the breakage mentioned in Mr. Gilchrist's paper is completely overcome.

This new development offers still other advantages. Keeping the slipper in full length contact with the socket affords full bearing engagement between slipper and socket. The degree of resilience which is characteristic of the special fabric enables the slipper to conform with the spade. Thus the great driving pressures are distributed over maximum bearing surfaces and the destructive effect of great pressures concentrated on limited bearing areas is avoided.

Furthermore, the pressure springs take up looseness caused by wear and permit slippers to be worn to a far greater degree before replacement than has been possible heretofore. Considering the great wear resistance of fabric slippers, as demonstrated by remarkable records already attained and substantiated by Mr. Gilchrist's report that there was very little wear, the self-aligning slipper bearings not only overcome the difficulties heretofore experienced, but also promise a tremendous increase in length of service.

K. T. McGILL: There is one point of particular interest, and that is the comment on the necessity of treating water in order to avoid roll neck corrosion and consequent rapid wear of the bearings. I would like to ask Mr. Gilchrist if he has found out whether the same acid condition has the same effect on rolls of different analyses; also whether improving the finish of the roll neck itself is a factor in resisting this corrosion.

We are doing some work along those same lines and we are trying to see whether the field practice is checking with the thing that we are learning in the laboratory. That's about the only comment I have as to whether or not Mr. Gilchrist could give any further light on that particular point, namely, whether the roll analysis was a factor in the corrosion.

H. R. GILCHRIST: There is no doubt in my mind that the type of roll neck has a great bearing on the seriousness of the acid condition. If we had a chromium-plated neck in the steel mill, I don't think we would have any trouble at all. As it is the acid itself has no effect on the bearing material; the roll necks pit after the acid content of the water becomes about 10 to 12 parts per million, and therefore it has to be limed. I believe that if we could change to a chromium-plated neck or something of that sort, we would get away from all that trouble.

K. W. ATWATER: One thing which is hard on composition bearings, where the roll necks have been running in babbitt or brass bearings is the fact that fine particles of the softer metals penetrate the pits on the roll neck surface, which in turn acts as a grinding wheel, even in localities where they have no acid in the cooling water.

I don't want to say so much about composition bearings themselves as I do about universal slippers. I personally believe that the trouble with the breakage of the slippers is due to similar causes which used to break composition and non-metallic bearings ten and twelve years ago. As most of you know, the design of those bearings had to be changed from the original design of brass or brass-babbitt bearings, the roll necks required a smoother surface finish, and the water sprays along the necks re-arranged or amplified, in order to get good practical and economical results. Such changes in design are now recommended for universal slippers made of composition material. I might point out just a few of the reasons why universal slippers made of composition material will break, and they do break in many mills.

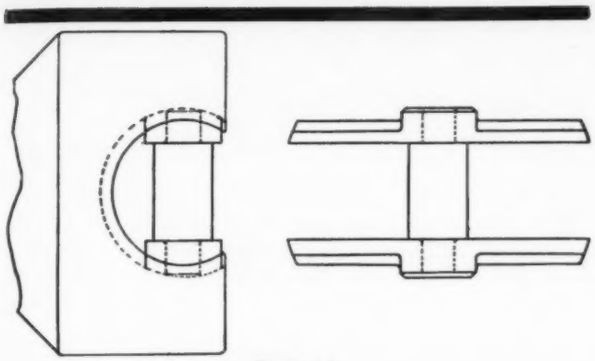


Figure A

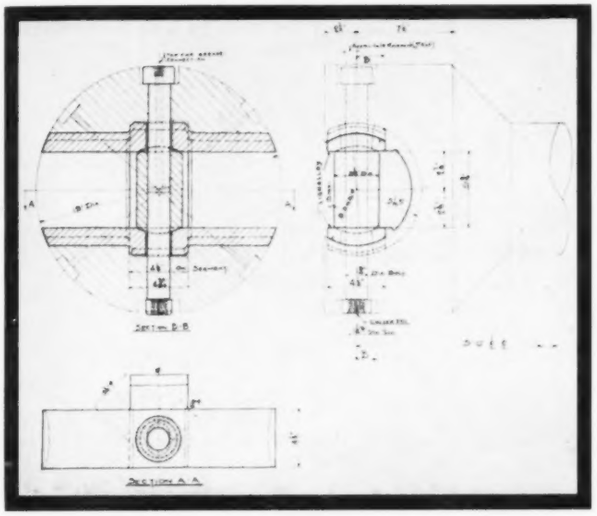


Figure B

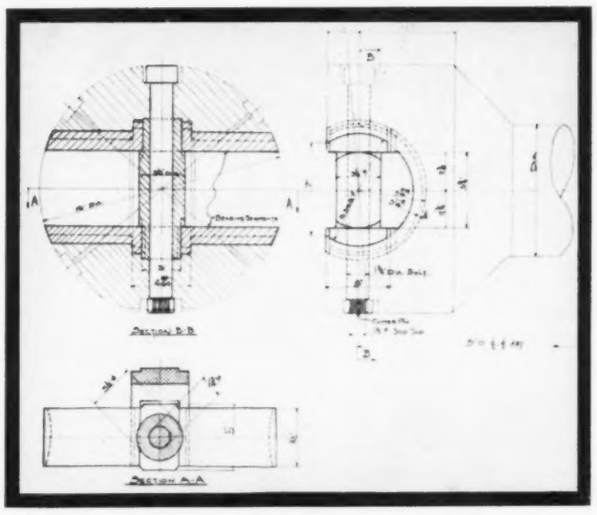


Figure C

The force of the spindle coupling comes always along the line of the fork of the coupling, and all this force is applied to a pin which is usually inserted between the two slipper halves, and anybody who has experience with slippers could always find that they break along a line diagonally across the pin hole in the slipper. (See Figure A.) That is due to the fact that the pin, which takes up practically all the force, works against it at a single point. If we know that the force is applied to this point, then the thing to do is to change the design in such a way as to distribute that force to some other points.

Figure B shows a slipper that is now in operation. A bolt extends through the coupling and slippers, and a swivel sleeve around the bolt between the slipper halves. Now if you arrange the slipper design that way, then the shock coming from the longitudinal direction of the coupling fork is not taken up directly by the slipper but by the pin and subsequently by the coupling.

Another way to do that would be to have the same arrangement with a pin extending through the slipper segments and coupling, by having each slipper segment made in two pieces. Figure C shows that the slipper parts cannot fly out of the coupling like they ordinarily would. In this case the forces that ruin the slippers have been transferred to the coupling, and I believe that slippers made in such a way would practically last forever (at least much longer than they do now), because it has been found out by comparisons that as regards length of wear, the better grades of composition slippers hardly wore out at all over a specific period, whereas brass slippers had worn themselves out over one-eighth of an inch during the same length of time.

And the other great advantage of universal slippers made out of composition material is not only that they operate the mills more quietly but that, as Mr. Rankin mentioned, the companion elements are not subject to wear. With the use of universal slippers made of composition material, coupling parts, or rather their surfaces, are continuously protected, and of course, it is less expensive to replace a slipper than a whole coupling. Of some importance is the fact that the much lighter weight of composition slippers, particularly in large type mills, facilitates greatly the assembly of the couplings, and means a great deal less work and worry for the maintenance man.

C. P. IRVIN: It is by publication of information of this kind and close observation by operators and manufacturers that we are going to have a continuation of performance life in composition bearings in the steel mills.

There was just one point that Mr. Gilchrist did not cover very completely in his discussion, although it is contained in his paper—one that I feel is very important—and that is the question of operating bearings without chamfers on. Inasmuch as most of the manufacturers of composition bearings supply them pretty largely in a standard width, I would like Mr. Gilchrist to discuss that point in order to enlighten us upon this matter, which I'm sure is one that most of you at least are interested in.

H. R. GILCHRIST: It has been found that chamfered bearings allow scale and dirt to get into the chamfer, resulting in a large amount of scoring of the necks. By doing away with the chamfer this source of scoring is removed.

H. C. IRVIN: As regards roll neck condition, we have made a rather thorough study of its effects upon the wear of non-metallic bearings. This study has carried us to the point of referring to roll neck roughness

(*Please turn to page 53*)

Factors of OPEN HEARTH Design and Practice

By WILLIAM C. BUELL, JR., *Steel Plant Consultant*
ARTHUR G. McKEE AND COMPANY
CLEVELAND, OHIO

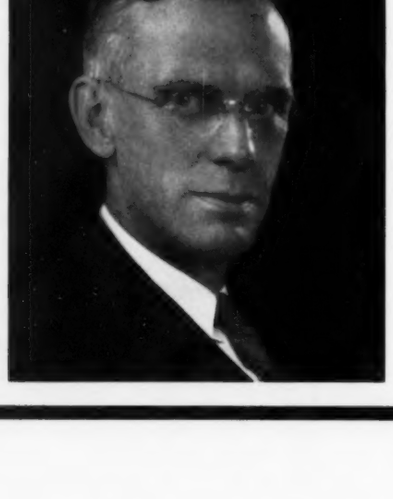
Presented before A. I. S. E. ANNUAL CONVENTION, CHICAGO, ILLINOIS, SEPTEMBER 24-27, 1940

▲ SO that this paper might be based on late practice, a rather lengthy questionnaire was developed in which data was requested upon which to base this paper. The questionnarie was sent to some thirty-five companies representing almost eighty per cent of our ingot producing capacity. The returns, the data from which have been freely used herein, were gratifying, and sincere appreciation is extended to the companies and individuals cooperating.

It should be clearly borne in mind that this paper refers solely to the manufacture of basic steel in stationary furnaces. It is taken herein that the manufacture of steel in the open-hearth plant is accomplished through the media of: 1—open-hearth furnaces; 2—an associated plant; 3—raw materials; and 4—a superior and local management and operating personnel.

No steel can be manufactured at any cost without some measure of participation of each of the four items, and optimum results concerning production, quality and cost can only be achieved, when all of the elements included in this schedule, exist on the highest plane.

W. C. BUELL, JR.



While optimum results are difficult of accomplishment here, as in any branch of producing industry, such results may be and are achieved.

FURNACE CAPACITY

Hearth volumes, or preferably ingot producing capacities of open hearth furnaces, as a feature of plant design are principally functions of soaking pit and blooming mill schedules and the probable steel grades and diversification of products that will be manufactured and marketed. Thus a plant designed for a production of say 80 per cent flat rolled products has a simple problem in determining the productive capacity of the open hearth units compared to the plant that will make and roll perhaps 35 per cent low carbon, 35 per cent medium carbon products and 30 per cent special and S.A.E. steels.

In the first case above, assuming an integral plant, open hearth furnace capacities may be relatively large but blast furnace casting schedules must be brought into the picture, particularly should there be limited mixer facilities. Further, soaking pit capacity must be considered with reference to its ability to receive ingots at the teeming schedules proposed, with the least loss of heat, and to discharge them, properly heated, in accordance with the blooming mill schedules.

In the latter case the open hearth furnaces should be of smaller capacities so that the many grades of steel may be made to the specified analyses without burdening the ingot bank with seldom called for steels. Differences of ingot track time, soaking periods and temperatures as well as the necessity of varying blooming mill technique to meet the different manufacturing and rolling specifications of purchasers of special steels, all have an important bearing on furnace size. The solution of this problem is mostly a study in materials handling, and scheduling.

It would seem that the capacity of the open hearth bath or the metal volume actually contained, has little or no effect on the quality of the steel made therein. Many of the S.A.E. grades are made satisfactorily in

150 ton furnaces. However, the bath dimension, particularly that of depth, may have some effect on steel quality especially when the fourth dimension, time, is integrally included.

Omitting free cutting steels, stainless steels, certain special grades such as high tungsten, and some forging grades, the entire range of commercial steels to include the S.A.E. grades are successfully and economically manufactured in the basic open hearth plant.

In the great majority of the hot metal plants, steel is usually made in furnaces tapping from 125 to about 200 tons and furnaces approaching the latter capacity appear to offer the optimum economic practice. Above this capacity the various limitations of plant and equipment particularly as regards charging and teeming, and difficulties with soaking pit and blooming mill schedules, are apt to nullify the advantages of the lower processing cost of the larger furnace units.

Following the start of the steel capacity expansion era which began about 1928 or 1929 a number of furnaces were built to tap more than 200 tons. Such furnaces were usually designed with 48 in. deep baths. Since original construction most of these deep baths have been reduced in depth and the tapping capacity of the furnaces lowered accordingly. Today hearths are seldom found that are much more than 36 in. deep. It was found that if satisfactory steel was to be made in the deeper baths an unduly long processing time was required for reasons which will later be apparent.

The depths of baths as herein mentioned are their greatest depths. The median depth of metal is usually about 60 per cent and the slag about 90 per cent of the depth values used.

Answering the specific questions, the operators having furnaces tapping 100 to 175 tons appeared to favor metal depths in the bath of from 20 to 32 in. when making low carbons with the majority specifying 28 to 32 in. but when making medium carbons or special steels they indicated a preferred bath depth about 2 in. greater than for low carbon steels.

The operators of the larger tonnage plants are unanimously of the opinion that furnaces having tapping capacities 150 to 175 tons are of the optimum size for satisfactory metal quality and economical maintenance, while several of those operating furnaces smaller than 100 tons express favorable opinions for 150 ton furnaces.

There is no question but that relatively deep baths of steel lengthen the refining and finishing periods appreciably. Assuming hearths of equal steel holding volume, it is apparent that the square footage of metal exposed to slag action per ton of steel contained will be greater with shallow baths and less with deep baths. Inasmuch as a tremendous amount of the refining action is accomplished at or near the interface of slag and metal, a relatively great interface area as found with the shallow bath, expedites the refining effect, saving considerable time.

Assuming a similar charge analysis it is obvious the total slag weight and volume must be the same to accomplish similar refining and thus with a deeper bath the thickness of the slag covering the metal will be greater. A thicker slag blanket increases the difficulty of heat transmission from the flame to the metal which means a greater operating temperature with more fuel and increased furnace maintenance cost. The extent to which temperature must be increased from greater slag depth is well indicated by the following typical example. Assume in both cases that the metal at the bottom of two baths is ready for tapping at 2900 degrees, and that the hearth refractories have like characteristics as regards thermal resistance. Then in the first case with a temperature drop through 30 in. of metal of 32 degrees and 4 in. of slag of 14 degrees, a total of 46 degrees, it follows that the temperature of the exposed surfaces of the slag must be at least 2946 degrees. In the second case if the metal bath is 48 in. deep the temperature drop will be 43 degrees and through 8 in. of slag, 28 degrees a total of 71 degrees, which develops a slag surface temperature of 2971 degrees.

While this is only 25 degrees higher than in the first case, it should be recalled that the average temperature of the furnaces gases over the bath may be lower than 3100 degrees and thus 25 degrees represents a considerable percentage of the temperature differential or thermal head, available for heat transfer to the bath. Recalling that heat transmission is in the order of the fourth power of the temperature differential, it is evident that small differences of temperature will create great differences in heat transmission. Thus with a temperature differential 3100−2946 degrees or 154 degrees as with the shallow bath, the transfer of heat from flame to slag will be almost 1¼ times as rapid as with the deeper bath condition of 3100−2971 degrees or 129 degrees differential.

The slag resistance to heat flow is about four times that of molten steel and consequently a thinner slag blanket is a distinct advantage to the speed and economy of the operation.

An investigation made a number of years ago developed this rather apropos data relative to the difference in the speed of production from furnaces of large capacity (200 to 350 tons) and deep baths (42 to 48 in.) and furnaces of about 150 tons capacity having 30 or 32 in. baths. The larger furnaces produced from 11.4 to 12.3 net tons of steel per 1000 cu. ft. of steel volume per operating hour and the 150 ton furnace from 15.3 to 17.2 net tons. The smaller furnaces with shallower baths were accordingly much more rapid producers.

The twelve furnaces included in the above study were from different shops but produced quite similar grades of steel, and therefore the values have considerable authority.

GRADES OF STEEL

Included in the questionnaire was a request for information as to the grades of steel made in the furnaces during the period covered by the answer. An effort was made to select the recipients of the questionnaire so that the coverage by steel grades would be quite complete. There were five divisions of grades specified in the questionnaire as follows:

1. Steel of 0.08 carbon or less;
2. Steel of 0.09 to 0.20 carbon;
3. Steel of 0.21 to 0.35 carbon;
4. Steel of more than 0.36 carbon;
5. Special steels.

The returns included plants making 98 per cent or more

in the first classification to one reporting 50 per cent in each of the fourth and fifth classifications. The totalized average of all plants reporting was: less than 0.08 carbon, 42.3 per cent; 0.09 to 0.20 carbon, 18.0 per cent; 0.21 to 0.35 carbon, 14.8 per cent; more than 0.36 carbon, 14.2 per cent; and special steels 10.7 per cent. It is thought that the coverage is entirely typical of the American steel industry.

PRODUCTION RATES

Time of heats and rates of production are interrelated to such a degree that they may well be discussed jointly. As a unit of comparative production rate and overall operating effects, the value, "production of steel, net tons per hour, per 1000 cu. ft. of metal volume," designated herein as "P" is used.

This places the results of the operation of all furnaces, no matter what their size in a directly comparable plane. Further, as this rating is founded on the metal actually tapped into the ladle it has as its basis the only really accurate and the most easily checked value of steel making practice.

During investigation of the comparative production values, a factor was quite accidentally developed which seems to offer the men of the steel-making fraternity an answer to their oft expressed wish for a simple method of qualitatively comparing various phases of furnace operation. The factor is as follows:

Let M = 1000 ft.^{3} of molten steel (base)
S = Tons of steel tapped per heat
T = Time of heat, hr.
lb = Lb. per ton (2000)
W = Weight of molten steel; lb. per ft.^{3} (430)
P = Tons steel made per hr. per 1000 ft.^{3} of bath

Then

$$P = \frac{M \times S}{S \times \left(\frac{\text{lb}}{W}\right) \times T}$$

or

$$P = \frac{1000}{\left(\frac{2000}{430}\right) \times T} = \frac{215}{T}$$

In order to use this comparison it is only necessary to remember the number "215" if you wish the comparisons in a net ton, or "192" for a gross ton basis. Now, if this factor is divided by the time of heats in hours (for example by 10 hr. 45 min. or 10.75 hr.) the answer will be (215/10.75 = 20) tons of steel made, per 1000 cu. ft. of hearth volume, per hour. This relation will hold true no matter what the furnace size may be, the grades of steel made, the fuel used or any difference in the practice plane.

Thus the factor offers a simple and easy method of making many interesting comparisons of furnace operation as for instance the productive rate of furnaces of different sizes, the effects for furnaces of like sizes working on different fuels or grades of steel, et cetera.

The net ton is the weight unit used through this paper. The weight of molten steel is taken as 430 lb. per cu. ft., and the time of heat as from charge to tap. Charge to tap time has been used rather than tap to tap time because it eliminates the variables of bottom making time and other ordinary delays. While of course any substitution of values may be easily accomplished it is evident that the general use of a single factor such as "215" would have many advantages, the greatest of which would be universal comparability.

FURNACE DATA

Table I here included contains certain collated data from the questionnaire, which pertains to the immediate discussion. There is much in this to interest, to confuse and to contradict. It offers an excellent example of the difficulty and danger of drawing other than very general conclusions of open hearth operation from any data even though it be carefully collected and well compiled. In this table, as throughout the paper, the several plants represented are designated by letter.

Of the twenty-one plants listed, eight plants reported on furnaces that are designated as "old." That is, they were mostly laid down on their present foundations twenty or more years ago, and have not since undergone any material modernization. Five plants reported on furnaces which were laid down many years ago but which have been redesigned and rebuilt to modernized design within the past few years as fully as building limitations will allow. These furnaces are designated as "rebuilt." The eight furnaces listed as "modern" have been constructed in new plants since 1929.

The number of heats included as a basis for the data indicate that the values range from the records of a campaign of a single furnace, to a year's average operation for several furnaces.

Furnace steel tapping capacities vary from 67 to 295 net tons. The arithmetical average of the capacities

TABLE I
EVALUATED DATA FROM QUESTIONAIRES

PLANT SYMBOL	ORDER OF FURNACE DESIGN	NO. OF HEATS INCLUDED IN DATA	BATH			IRON		PRODUCTION				FUEL
			TAPPING CAPACITY NET TONS	METAL VOLUME Ft.[3]	METAL DEPTH INCHES	TOTAL CHARGE %	Si IN HOT IRON %	LOW CARBON STEEL TIME OF HEATS/HR	P_1	MED CARBON STEEL TIME OF HEATS/HR	P_2	KIND
HOT METAL PRACTICE												
A	OLD	438	68.2	312.9	30	57.0		8.25	26.1	8.84	24.3	LIQUID
B	OLD	7589	91.3	424.7	34[a]	38.9	1.05	9.67	22.2	9.00	23.9	LIQUID
C	OLD	1321	131.0	609.3	31	47.7	1.05			10.20	21.1	LIQUID
D1	OLD	6181	142.8	664.2	36[a]	42.7	1.05	12.66	16.6	12.16	17.7	LIQUID
E	REB'LT.	4300	152.3	708.4	36[a]	35.0	1.00	12.00	17.9			NAT. & C.O. GAS
F	MODERN	425	156.8	729.3	28	60.0		12.16	17.7			PRODUCER GAS
D2	MODERN	4806	171.5	797.7	37[a]	41.4	1.05	12.66	16.6	12.16	17.7	C.O. GAS & OIL
G	MODERN	375	173.6	807.4	28	58.0		12.00	17.9	12.00	17.9	PRODUCER GAS
H1	MODERN	1075	190.0	883.7	28	45.0	1.10	11.00	19.5	11.50	18.7	B.F. GAS & OIL
H2	MODERN	350	190.0	883.7	28	45.0	1.10	11.00	19.5	11.50	18.7	B.F. & C.O. GAS
I	REB'LT.	3748	194.3	903.7	38[a]	33.8	1.00	12.00	17.9	11.75	18.3	LIQUID
J	REB'LT.	1676	195.9	911.2	30	61.0	1.10	11.64	18.2			PRODUCER GAS
K	MODERN	4880	198.0	920.9	28	36.9	0.75	8.16	26.3			LIQUID
L	MODERN	600	201.7	938.1	38[a]	55.0	1.10	11.00	19.5			LIQUID
M	REB'LT.	1836	207.2	963.7	28	53.9	1.00	11.66	18.4			LIQUID
N	OLD	230	295.0	1372.0	41[a]	60.0		15.50	13.9			PRODUCER GAS
COLD METAL PRACTICE												
R	OLD	4854	69.6	323.7	28	23.0		9.50	21.7			LIQUID
S	REB'LT.	335	114.3	531.6	24	42.5		11.80	18.2	11.80	18.2	LIQUID
T	OLD		121.0	562.8	22	20.0		12.00	17.9	12.00	17.9	H.G. & OIL
U	OLD	420	123.4	574.0	36[a]	12.0		11.50	18.7			LIQUID
V	MODERN		134.6	625.1	30	15.0		13.66	15.7	13.33	16.1	LIQUID

[a] AT DEPTH INDICATED STEEL IS ABOVE FORE PLATE LEVEL

of the hot metal furnaces is about 172 tons and of the cold metal furnaces about 113 tons. Steel volume is calculated by multiplying tons of steel tapped by 2000/430, or 4.65.

The depth of metal is as reported. Those values followed by an asterisk indicate the level of the molten steel in the bath at tapping time is above the foreplate. This is usually an indication of an attempt to force production.

The per cent iron charged is that as shown by the figures reported and varies from 41 to 61 per cent in hot metal practice and from 12 to 42 per cent in cold metal practice.

All plants which reported on the silicon in the hot metal, excepting plant K, gave values of from 1.00 to 1.10 per cent. This favorable uniformity is greatly at variance with the values usually quoted by the open-hearth operating men.

Such silicons indicate remarkable iron making practice, and it is feared we may have offered our friends the blast-furnace operators a valuable bit of advantage in our running argument. Something further will be said later on the subject of silicon in basic iron.

In the questionnaires, information was requested on time of heats covering the five grades of steel. Examination of the answers is rather surprising. Plant A reported a spread of one hour and 40 minutes difference in time of heats between all grades; plant I one hour and fifteen minutes; plant V one hour and ten minutes; while the balance of the plants reporting on all grades show one hour or less total spread. Some plants reported less time on low carbon steels while others reported less time on high carbon steels. It thus was found impossible to make the comparisons of time of heats it had been hoped and consequently time of heats will be found in only two groupings: the first, carbon steels of less than 0.20 carbon, and the second, medium carbon steels of more than 0.35 carbon.

The comparative productive values are found through the evaluation of the constant "215" and shown in columns headed P_1 and P_2 respectively.

It is interesting to note that, excluding the results from plant K, the mean P of the hot metal furnaces is 18.7 when working on low carbons and 19.8 when working on medium carbons. Thus the time of heats is about 5½ per cent faster for the latter classification.

The mean *P* of the cold metal furnaces is 18.4 for low carbon heats and 17.4 for medium carbons. Thus the results from the operation of the cold metal furnaces reverse these reported for the hot metal furnaces which would seem to be inconsistent.

The kinds of fuels used are quite diverse, with liquid fuel predominating. Producer gas values are calculated less the producer losses which are in all cases taken at 20 per cent. For the furnaces operating on hot metal, the fuel rates vary from 2.850 million to 4.820 million Btu. and for all cold charge from 4.018 to 5.820 million Btu. per net ton of product.

Six furnaces working on hot metal are cited as having fuel records of less than 3.5 million Btu. per ton of steel over a considerable number of heats. Quite a variety of fuels are employed and the furnaces, excepting furnace I, have shallow baths. As they form an interesting group for further examination, certain data are abstracted from Table I and repeated here in Table II.

TABLE II

SIX PLANTS WITH EXCEPTIONAL FUEL RECORDS

PLANT SYMBOL	NUMBER OF HEATS INCLUDED IN DATA	BATH		PRODUCTION P_1	FUEL	
		TAPPING CAPACITY NET TONS	METAL DEPTH INCHES		KIND	CONSUMPTION MILLION B.T.U./N.T
H_1	1075	190.0	28	19.5	B.F. GAS & OIL	3.274
H_2	350	190.0	28	19.5	B.F. & C.O. GAS	2.900
I	3748	194.3	38*	17.9	LIQUID	3.380
J	1676	195.9	30	18.2	PRODUCER GAS	2.945
K	4880	198.0	28	26.3	LIQUID	2.850
M	1856	207.2	28	18.4	LIQUID	3.125

The significant features of the data of Table II appear to be that these low fuel values are made with representative types of fuels including producer and blast furnace gases and, with a single exception, in furnaces having shallow baths.

In an effort to determine if any regularity exists in the relation of furnace size and productive capacity, certain data from Table I were plotted in the chart, Figure 1. Had the record of plant K been omitted the trend lines a-b, for hot metal heats and c-d, for cold metal heats might find considerable substantiation. For ordinary practice as found in most plants, the trend lines are likely to be fairly representative, and if so, smaller furnaces are more rapid producers on a comparative basis.

This feature is quite definitely indicated by the "*P*" of furnaces A and B of the hot metal group and furnace R of the cold charge group. All of these furnaces are of greater age and an older order of design than most of the larger furnaces, but they produce steel up to one and one half times more rapidly than the larger furnaces.

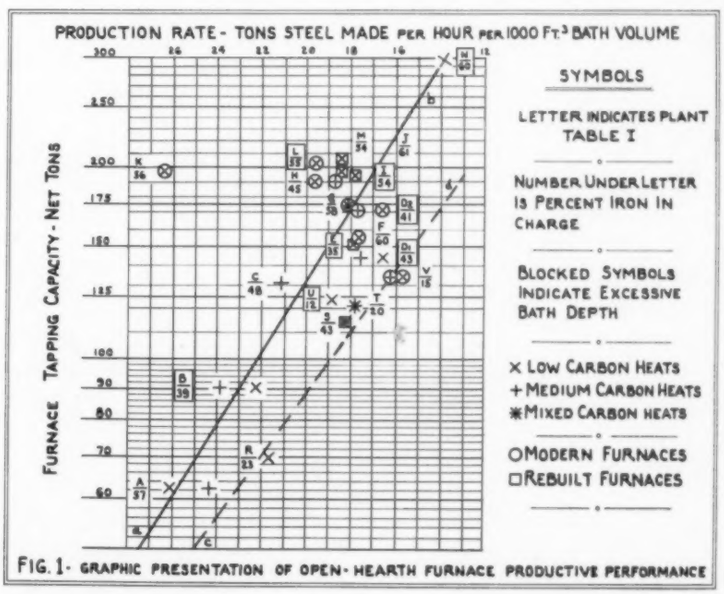

PRODUCTION RATE - TONS STEEL MADE PER HOUR PER 1000 FT³ BATH VOLUME
FURNACE TAPPING CAPACITY - NET TONS
SYMBOLS
LETTER INDICATES PLANT TABLE I
NUMBER UNDER LETTER IS PERCENT IRON IN CHARGE
BLOCKED SYMBOLS INDICATE EXCESSIVE BATH DEPTH
× LOW CARBON HEATS
+ MEDIUM CARBON HEATS
✱ MIXED CARBON HEATS
○ MODERN FURNACES
□ REBUILT FURNACES

FIG. 1 - GRAPHIC PRESENTATION OF OPEN-HEARTH FURNACE PRODUCTIVE PERFORMANCE

It is also a fair guess that the trend lines as drawn give an indication of the changes in steel making speed accruing, in a general way from differences in bath depth as it is inherent that smaller furnaces have shallower baths and larger furnaces deeper baths. It should be noted that these lines are plotted on a logarithmic scale and as drawn are actually second degree curves.

The lines indicate clearly the greater productive speed of the hot metal processes when compared to the cold metal process and give a good idea of the difference in the speed of the two processes. Thus with 150 ton furnaces the hot metal process appears to be about 25 per cent faster than the cold metal process. This differential appears to decrease as the furnaces become smaller.

The value of this paper would be greatly enhanced if you would evaluate your own practice in accordance with the method here used, and add it to the chart of Figure 1.

SILICON

At last we appear to be giving serious consideration to the effect of silicon in basic iron above a minimum, as a major cost problem, which it has ever been. It is the author's opinion that the elimination of excessive silicon is one of the most if not the most costly item of the furnace phase of steel making. Excessive silicon increases the requirement of limestone; heat time is much longer; added fuel is required, and furnace maintenance cost is substantially increased. The foregoing comments of course refer particularly to hot metal plants.

The chart, Figure 2, contains much illuminating information with reference to the fluxing of silicon. If the endpoint of silicon in the slag is assumed as tricalcium silicate, and the iron in the charge is 60 per cent, then it may be found that fluxing 1.0 per cent silicon in the iron component requires not less than 160 lb. of limestone per ton of metallic charge, and of course 2 per cent silicon requires double that figure. One per cent phosphorus in the iron requires but 88 lb. of limestone per ton of 60 per cent iron charge and thus in order to flux phosphorus to tricalcium phosphate, it is plain that silicon, in view of its abundance, rather than phosphorus, or even sulphur, is the metalloid that effects furnace operating factors to the greatest degree.

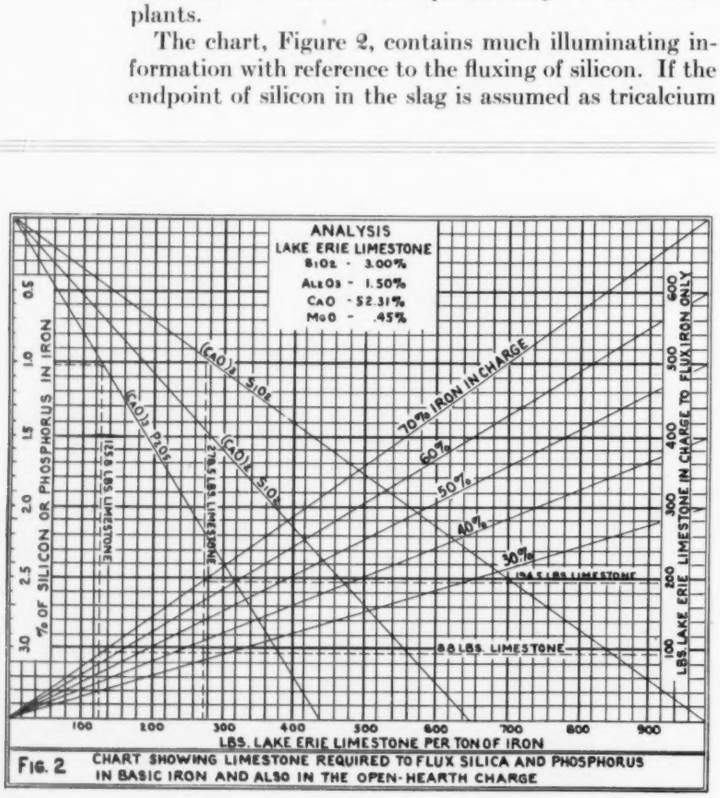


FIG. 2 CHART SHOWING LIMESTONE REQUIRED TO FLUX SILICA AND PHOSPHORUS IN BASIC IRON AND ALSO IN THE OPEN-HEARTH CHARGE

CONTROL

The questionnaire inquired about furnace control in some detail. Of the operators reporting, 88 per cent used draft control; 62 per cent, some form of reversing device or reversing indicator; 31 per cent, roof temperature control, and 23 per cent, fuel-air ratio devices.

In reply to the question as to the relative value of control to operations, 56 per cent cited draft control as the most valuable; 18 per cent reversing control; 6 per cent roof temperature control and 12 per cent fuel-air ratio devices.

The final question asked the operators personal opinion as to the most valuable features of design, construction or operation that have developed over the last 15 years and are used in their own practice—only 32 per cent included any phase of furnace control in their comments on this question.

The answers to this question were extremely interesting and varied. Six operators chose combustion improvement either as a result of furnace redesign or through the installation of patented equipment. Four operators named slag control. Four selected some phase of furnace control; and single operators named respectively, pit practice; insulation; improvement in refractories; improvement in raw materials; larger heats (to reduce costs); and shallower baths (to increase production and improve quality).

RELATION OF FURNACE DESIGN AND FUEL APPLICATION

There are perhaps six different fuels commonly used for firing open hearth furnaces, namely, producer gas, natural gas, coke oven gas, tar, fuel oil, and various refinery residues, and in addition a few plants use blast furnace gas as a part of the open-hearth fuel. Nearly all of these fuels are often fired in various combinations. Witness the data on this subject, Table I.

There are but three principal types of furnace design with respect to the fuels which are commonly used: One type for producer gas firing; a second type for the employment of blast-furnace gas, fired in combination with a richer fuel; and a third type suitable for the use of the richer fuels only.

The necessity for these different types of design is due entirely to the changes in the relative volumes of the

products of combustion inherent to the chemistry of the various fuels.

Assuming an equal heat release in a unit of time, the relative volumes of the gases developed by the process, flowing in an open-hearth furnace, are about of the following order:

Oil or tar	1.00
Coke-oven gas	1.02
Natural gas	1.09
Mixed gas*	1.21
Producer gas	1.43

Superior thermal effects can be accomplished only when the gases of the process move within the various elements comprising the furnace system at closely defined velocities.

The defined velocity through any element of the furnace system is substantially a constant no matter what fuel is employed, and consequently the need is obvious for modification of the areas governing gas flow.

Especially is the foregoing true if the unit production rate is to be maintained in similar cases, for a somewhat increased primary heat input is usually necessary to accomplish this effect as the fuels become leaner.

It is without the scope of this paper to consider any details of furnace design, but it may be stated that with the exception of the port of a producer or mixed blast furnace gas fired furnace, all details of design may now be solved by the application of simple mathematical principles.

RECAPITULATION

Open hearth steel making or ingot cost is affected by four cardinal items inherent to the art, and several important secondary factors, which may be listed about as follows:

1. *The Furnace:*
   a. General design and construction
   b. Bath depth
   c. Fuel
   d. Maintenance and repair
   e. Control operation
2. *The Plant Layout:*
   a. Charging facilities
   b. Abutting department facilities
3. *The Iron and Raw Material Supply:*
   a. Quality
   b. Consistency of iron analysis
4. *The Personnel:*
   a. Operating
   b. Management and interdepartmental
   c. Metallurgical
   d. Mason
   e. The order of cooperation

It will be noted that these are not listed in the order of their importance for the simple reason that each item is of equal importance to the overall scheme of operation if optimum results are to be secured.

It might be well to consider the effects or conditions of these several items on the overall practice.

1. If the furnace has been liberally designed and constructed in accordance with our present day knowledge of the subject and the proper size has been selected, then the first important step has been taken reaching towards superior operations.

It is believed that the relatively shallow bath of metal is essential for rapid operation. Thirty inches of metal should be the maximum bath depth for larger furnaces of say 125 to 200 tons capacity, and possibly 24 or 26 in. for those under 125 tons capacity.

It is generally accepted that certain lean fuels, particularly producer gas, are slower as processing media and require a greater heat expenditure than the richer fuels such as oil or coke oven gas. While it seems reasonable to expect a time or heat loss up to perhaps 10 per cent, when the leaner fuels are used, the performance at plant J, Figure 1, and Table I, is a refutation of this idea.

After a few hundred heats, the best of furnace design and construction will avail little if maintenance and repair is not established and carried out on a plane parallel to that of the original design and construction. Rebuilds must be accomplished on the premise that when a furnace is returned to production it must in all respects be as nearly in its original condition as it is possible to make it.

Control of the furnace operation, whether manual, instrumental or in part both, must be on a plane commensurate with that employed in the furnace design and construction otherwise any advantage accruing from the installation of a good furnace may be totally lost.

Based on a considerable knowledge of conditions in a great many plants, the author feels secure in offering the opinion, that in no shop, more than twelve years old, can existing furnaces be redesigned or rebuilt to develop the economies found in most of the new shops constructed within that period.

2. The effects of plant layout have not been discussed before, but proper plant layout has a most important bearing as regards the productive rate of the contained units. It is not believed it is possible to secure the maximum production from a shop unit if the shop contains more than six or seven furnaces.

Every furnace has a time constant at which it can be counted on to produce steel. Time in excess of the production constant is often the result of platform delays of transportation, scheduling and charging and these delays mount up as the number of furnaces in line increase. A study was made several years ago of materials handling delays in a twelve furnace shop and it was then definitely determined that, over a reasonable period of time, as great a tonnage of steel could be produced with from nine to ten furnaces operating, as could be produced when twelve furnaces were under heat, and even with nine furnaces operating, there were substantial platform delays. Six or seven furnace operations should reduce materials handling delay to near the zero point.

3. As the ratio of the iron component of the charge becomes larger, it is increasingly important that it be a product of the best blast furnace practice possible, if optimum steel making practice is to be achieved.

This means real interest and cooperation by the blast furnace operator, who incidentally has some very real

*240 Btu. per cu. ft., mixed blast furnace and coke oven gas.

problems of his own. The item of the phosphorus content of the ores to be used and subsequently appearing in the iron is generally without his jurisdiction but the control of sulphur and silicon in the iron is definitely in his hands. The elimination of sulphur in the open hearth process is difficult and costly, but it can be more easily controlled at the blast furnace. Low sulphur should be the open hearth operators very rigid and principal specification.

Low silicon iron should be the second principal specification. The blast furnace operator will generally hold that he can not produce low sulphur and silicon jointly. While this idea is subject to debate, low silicon iron is one of the greatest aids to the steel maker's productive and cost records.

After thoroughly studying and considering the effect of silicon in iron on steel making practice the company with which the author is associated is now prepared to offer a process intermediate to the blast furnace and open hearth for the control of silicon. This process should prove very beneficial to steel making practice and costs when the swing of silicon in iron extends much above one per cent and cannot be otherwise corrected.

4. Obviously the most carefully designed and constructed furnace; the most painstakingly laid out plant, or the finest of iron and raw materials will avail little, unless the operation is conducted on the highest plane by competent and foresighted managing, purchasing, operating, inspecting and maintenance personnel, supported in the fullest degree by the correlated participating plant units which are the blast furnace and the blooming mill departments.

The consummation of the above is very difficult, for it means that probably at least a dozen individuals with widely assorted training and capabilities must be so imbued with the spirit of cooperation and achievement as to make an almost perfect team. This is an accomplished fact in far too few instances.

The ideal of open hearth practice is very probably impossible of achievement and the optimum practice may be achieved only if the four cardinal and various important secondary factors heretofore enumerated are integral to the practice in the fullest degree of perfection possible.

Numerical index numbers totalling 100 assigned to the four cardinal items of the practice may be assumed as indicative of an ideal. Even though such values be arbitrary and without adequate support, they offer a basis of discussion. Thus:

1. *The Furnace*.....Index No. 30
2. *The Plant*.....Index No. 10
3. *The Raw Materials*.....Index No. 20
4. *The Personnel*.....Index No. 40

The ability of the human race being measured by its weaknesses, it is probable that the ideal as expressed above is unattainable at least in all the divisions but an overall optimum of say 80 is attainable and in the author's opinion has been substantially attained in at least one instance.

Let is be assumed that a better than average plant might rate an index of 60, and it is the author's further opinion that this is a fair figure for many if not most of the better plants; then such an overall operation will merely fall into the area of mediocrity from which it can only be raised to a higher plane by radical reconstruction and rearrangement of plant and equipment, and changes in general policy or personnel.

The unit production rate is probably the best indicator generally available as to the relative merit of steel making practice. From records which have been available in confidence at various times and therefore unfortunately, can not be cited, it is evident that overall steel making cost; after giving effect to appropriate modification for market and other local conditions, with furnaces having similar capacity, follows the unit production rate very closely. It is well to re-examine Table I and Figure 1, particularly the latter for substantiation of this general idea.

The chart shows the great majority of the furnaces of larger size to be producing at rates from about 15 to 20 net tons, per thousand cubic feet of metal, per hour, with the smaller furnaces producing at materially higher rate, but unquestionably higher cost.

Quite likely the line a-b might well be considered to represent an index of 60 for the hot metal plants and the line c-d a similar value for the cold metal plants, and both lines might also be considered as representa-

tive of the region of mediocrity in their respective practices. In order to better practice, these lines obviously must be relocated substantially towards the left of the chart.

Thus all of the plants examined, excepting plant K, fall into the region of mediocrity. In the author's opinion plant K, which is far to the left of the trend line, closely ranks the superior rating of an overall 80 index value.

It is dangerous to establish conclusions of any sort on a basis of the performance of a single unit, but in justification of so doing, it is well to consider certain unusual conditions in this instance. Plant K is the only open-hearth shop in the country of which the author has data that even remotely approaches the optimum of operating performance. Its record for fine operation and low cost has been maintained for a sufficient period to establish the fact that it is not a sudden and unaccountable phenomenon but the result of a gradual and carefully developed and executed betterment program extending over more than 10 years.

Let us "read" the records and data of furnace "K" on the cardinal items of open hearth operation and endeavor to find to what extent this practice fulfills the optimum tenets as stated.

1. *The Furnace:* In this plant the furnaces were constructed about 1930 and incorporate much of the design and equipment that are now considered to be necessary or desirable in an open hearth furnace. Under the definition they are "new" furnaces, and could well be placed at 80 per cent of the index ideal.

2. *The Plant:* This is a six furnace plant with ample transportation and materials handling facilities. This feature would rank nearly 100 per cent.

3. *The Charge:* Averages 56 per cent hot metal which contains less than 0.75 per cent silicon and 0.04 sulphur. Purchased scrap would appear to be below the mid-west average. A 90 per cent rating would be conservative here.

4. *The Personnel:* Based on an acquaintance with several members of the management and operating staff of this plant, the author would express the personal opinion that as individuals they are fine executives and technologists, and may be unique as a group in that to all appearances they incorporate and practice the fundamental idea that, to paraphrase Shakespeare, "The plant and not the department is the thing." The author has not the temerity to suggest an order of perfection in this division.

Each open hearth shop is but a unit of a steel manufacturing plant, and while the open hearth personnel can do many things to better quality and cut costs, as they have done in the past and will continue to do in the future, they are totally at the mercy of the policy making group and to a lesser degree to the abutting departments of the complete organization.

Thus may it be suggested to the superior management of any plant: "If you are interested in a substantial reduction in the cost of better steel, your self-analysis of your plant, along the lines employed herein, should indicate how an 80 index may be approached and perhaps accomplished."

DISCUSSION

PRESENTED BY

G. M. COUGHLIN, *Combustion Engineer,* American Rolling Mill Company, Ashland, Kentucky.

H. T. WATTS, *Combustion Engineer,* Republic Steel Corporation, Gulfsteel District, Gadsden, Alabama.

F. E. LEAHY, *Fuel Engineer,* Youngstown Sheet and Tube Company, Campbell, Ohio.

W. P. ALBAUGH, *Superintendent,* Open Hearths, American Rolling Mill Company, Ashland, Kentucky.

R. I. GUMAER, *Fuel Engineer,* Jones and Laughlin Steel Corporation, Aliquippa, Pennsylvania.

C. E. HAGUE, *District Representative,* Askania Regulator Company, Cleveland, Ohio.

W. C. BUELL, JR., *Steel Mill Consultant,* Arthur G. McKee and Company, Cleveland, Ohio.

G. M. COUGHLIN: I think Mr. Buell has given us some excellent thoughts. If we could examine our furnaces in the light of the curves he has shown, especially the last one, we might be able to do something about it. He has accused most of us of having obsolete plants. Perhaps some of you disagree. He has certainly given the twelve-year old, and older plants, a challenge. I think possibly some will accept the challenge.

In speaking of the depth of bath there certainly is a broad range in depth of bath in the furnaces of this country. It seemed the lower in carbon you go in the analysis of the steel made, the shallower should be the bath. I wonder how shallow the bath should be for those people who make a lot of ingot iron. What would be the optimum for that?

When Mr. Buell speaks of tons, he is speaking of net tons. This figure of 215 refers to the net ton basis. On the gross ton production, of course, the figure would be 192.

Another thought he brought out was the question of silicon. He seemed rather skeptical about the information received as to the silicon in the open hearth received from the blast furnace. Perhaps someone would not mind telling what can be done to control this higher silicon the blast furnace sends, so you won't put more than one per cent silicon in the furnaces. That is a very interesting thought. Mr. Buell will perhaps later give some idea as to this substitute for soda ash which he is talking about.

H. T. WATTS: An item of considerable interest is the formulated value entitled "production rate per unit tapping volume," specifically, tons per hour per 1000 cu. ft. steel tapped per heat, which Mr. Buell utilizes to show the effect of the many variables upon productive rate.

Inasmuch as the wide range of furnace sizes renders the bare figure of tons per hour, in most cases, quite valueless as an indicator of excellence in design or operation, it was necessary to relate this figure to some dimension of the furnace. In relating this to the tapping capacity, the author has obtained a result in keeping with the long-held opinion of many furnace operators,

that the only gauge by which to measure a furnace production is the time of heat. They expect a large furnace to deliver a heat in the same number of hours as are required by a small furnace, often to the great discomfiture of those trying to aid in the delivery of the heat to the bath.

The formula for the factor P states that comparative productive rates vary inversely as the time of heat, but a proportionality factor 215 is inserted to embody into the relation the actual tons per hr. and tapping capacity in cu. ft. It becomes clear that P is equal to the number of heats made in 215 hr. operating time. A factor P equal to 1 is indicated for a furnace making heats in 215 hr., and a factor P equal to 20 is given a furnace making heats in 10¾ hr.

Since standardization of open hearth furnaces will likely be consummated on some such lines, it appears advisable to suggest a unit of greater magnitude, which may make relative performance of furnaces more readily comparable. Consider a factor "tons per hr. per 50 cu. ft. of tapping volume," in which the unit is twenty times as large as the unit proposed in the author's paper. The relation would then become "P equals $10.75/T$," giving a factor P equal to 1 for a furnace delivering heats in 10¾ hr. Other furnaces would fall above or below the factor 1, according to their time of heats, and the divergence from the factor 1 could be measured in percentage points, whose relation is more easily appreciated than the relation to each other of such numbers as 16, 18, etc. Since 10¾ hr. per heat is probably considered neither slow nor fast time, it might be fixed as a basic time of heat. The comparative production factors for other furnaces evaluated in terms of this larger unit would appear in percentage of the 10¾ hr. standard and would be not unlike the factor called "per cent of rating," universally used to show comparative performance of steam boilers. It is unfortunate that the open hearth furnace appears to offer no such definite basis as heat input per hr. per sq. ft. of absorbing surface, as in the case of the boiler. The system of comparison proposed by the author and as slightly amended by the writer, is probably best justified by the fact that it yields results in line with the opinion of many operators who, as stated above, believe that furnace productive performance, regardless of size of heat, should be judged solely by time of heat.

Without presuming to thoroughly discuss the data, which has been so capably dealt with by the author, we nevertheless cannot avoid mention of one general trend which is visible to the naked eye. Arithmetical averages of rearranged data from Table I indicate the following facts:

Average tapping capacity increased from 130 tons on old furnaces to 173 tons on rebuilt and 173 tons on totally new furnaces. The average metal depth was 32 in. on the old, 31 in. on rebuilt and 31 in. on the new furnaces. Surprisingly, the time of heat is slightly greater on the rebuilt and the new furnaces than on those termed "old furnaces," the factor P being 19.0 for old, 18.1 for rebuilt and 18.0 for new furnaces on low carbon heats. Because it appears to be out of the general line-up, plant K was omitted from these averages.

Since we believe the data is reliable and the basis of comparison correct, we must conclude that so far as these groups of furnaces are concerned, whatever other improvements and economies have been made in rebuilding old furnaces and constructing new furnaces, such treatment has not been effective in increasing comparative production rate, defined as tons per hr. per 1000 cu. ft. of tapping capacity.

Inasmuch as the sizes of rebuilt and new furnaces shown are decidedly larger than those listed as old furnaces, possibly the decrease in comparative production rate is due to inability to effect maximum heat absorption over the entire length of the longer furnaces.

F. E. LEAHY: One of the things running through my mind is the number of factors which enter into satisfactory production and good operation.

Also, I noticed that he mentions that in some cases they reported that slag control had quite an effect. We have felt, at our plants, that the use of slag control has been a very excellent factor in getting the desired results; and where the delays are low, furnaces charged up promptly after they are tapped out, and similar practices, we invariably get very good practice for the plant and the equipment.

W. P. ALBAUGH: I was quite interested in Mr. Buell's paper, because at the present time we are enlarging one of our furnaces—you might call it rebuilding it—and we are increasing the depth of our bath approximately 10 in. to see if we can increase our tons per hr. and get the benefit from that.

In regard to this remark of Mr. Watts', where he said the modern furnaces showed lower tons per hr., and the older furnaces showed better tons per hr., was that derived from the table in the paper?

H. T. WATTS: My remark was to the effect that the tons per hr. per 1000 cu. ft. of tapping volume, in the particular group of furnaces shown on Table I, were less on the larger furnaces. The new furnaces and rebuilt furnaces showed fewer tons per hour per 1000 cu. ft. of tapping volume than the old furnaces.

W. P. ALBAUGH: I wondered if that was due to furnace design, or if it would be more in the method of operation or the handling of equipment, which Mr. Buell said was so important. I think the heat transfer in the newer, modern furnaces, is quite important. Their operation is above anything I have ever seen in the country. You take a furnace that is modernized in an old shop, and you may not be able to get all the advantages you would expect out of six modern furnaces in a shop that is new.

R. I. GUMAER: I was particularly interested in the part of the paper dealing with the percentage of these furnaces that had the various control items. For example, so many per cent had draft control, another so many per cent had roof control, etc. I wonder if he could break that down into the furnaces fired with producer gas; what per cent of those furnaces particularly had the fuel-air ratio control?

C. E. HAGUE: Mr. Buell's paper brings up a great many questions which could be argued pro and con. I note, however, the percentage of replies concerning the various items of control are roughly in proportion to the control items in use, the pressure controls being greatest in number, etc. I think it is interesting, and possibly significant, that the very great spread between the practice in the old furnaces and the new furnaces may at least have some relation to the fact that on newer

furnaces the more complete control is to be found. Also, in the newer plants, personnel may have been added to get the greatest use from the control, and to study its possible influence on design, and it is probable in these newer plants the advantage of newer design may be influenced by the control.

W. C. BUELL, JR: A few comments on Mr. Coughlin's discussion of my paper: I feel that all the available evidence definitely indicates that a shallower bath of metal is a faster refining bath. Some of the possible reasons for this are pointed out in the paper and others will occur to most of us.

My company is in no manner interested in the beneficiation of iron between blast furnace and open hearth by ladle addition. We are, however, working in a preliminary way, on an iron refining process which is an intermediate step through which the iron introduced into the open hearth, is of the most favorable analysis and in the best physical condition for its most economical conversion into steel.

Mr. Watts' analysis of the factor "*P*" is most interesting. His statement that we have not increased production rates as against the unit of 1000 cu. ft. of metal, in enlarged furnaces, appears in general, to be amply supported. I believe, however, the answer as to why production rates do not increase may be found through appropriate evaluation of the data presented.

I feel that the factor "*P*" offers a base for the comparison of almost any feature of operation. Mr. Watts mentions his wish for a comparative basis of heat input per hour. Such may be had if "*P*" is multiplied by the unit fuel rate per ton of steel, which is given in the last column of Table I. The resulting factor, which might well be designated "*F*" is, heat input, per 1000 cu. ft. of bath per hour.

The solution of "*F*" for the furnaces included in the paper, produce some extremely interesting data regarding the relation of fuel input and steel produced which if referred to an optimum fuel practice such as 3.5 million Btu. per ton of steel, will very definitely point to the quality or effectiveness of the use of fuel in the open-hearth at the particular plant, and further indicate the necessary means to increase unit production.

I judge the gist of Mr. Leahy's remarks refer particularly to the advantages of rapid charging. Obviously a delay in spotting the charging drag before a furnace when it is ready to charge, is production time that is irrevocably lost. Proper scheduling of and arrival of the materials at the furnaces is one of the very first requirements of modern practice.

In reply to Mr. Albaugh: When a furnace is enlarged, it is usually true, that production when converted to the 1000 cu. ft. of bath unit, is actually lowered.

Assume the case of a furnace producing 150 ton heats in 10.75 hours or that $P = 20.0$. If the tapping capacity is increased to say 200 tons then the heats must be produced in 10.75 hr. to maintain $P = 20.0$. Any increase in heat time will reduce P. If the larger heats are tapped in say 12.0 hours, then $P = 18.0$. Something similar to this is the ordinary experience with enlarged furnaces, and the reason is commonly found in the following set of circumstances: Any furnace is usually operated at its maximum fuel burning capacity. The maximum fuel burning capacity has generally been arrived at through a careful study of a furnace, and ports, throats, checkers, valves, etc., which may have been altered or improved so as to give optimum results in the particular unit when producing at a normal tonnage rate. As increased production in the same time of heats calls for a nearly proportionate increase in the fuel burned per unit of time, it should be obvious, that so long as any important element of the furnace or its system, remains unenlarged to the proportionate tonnage increase, the production of the enlarged furnace must be relatively abridged.

A reduction in fuel rate is only another way of showing improvements in fuel utilization and particularly heat transfer effects. Twenty-five years ago fuel rates were 6 to 7 million Btu., ten years ago 4.5 to 5 million, and now in the best practice below 3.5 million. To me this indicates we are correctly applying the theory of heat transfer effects.

To Mr. Gumaer I would comment that without the primary advantages of fully controlled modern mechanical producers, control of any phase of producer fired furnaces is of doubtful value.

As to his request for the breakdown of the control devices used in the four producer gas fired shops reporting: All four shops reported on furnaces equipped with pressure control, three on furnaces equipped with reversing control and one each on roof temperature control and fuel-air ratio.

I have received two criticisms which I should like to answer here. The first of these concerned the high P, 26.1, for old and small furnace A which is nearly as great as that, 26.3, for modern and large furnace K. The solution of this will be found in the fuel consumption of the two units. Relative to the P value of 26.1, furnace A is consuming 125 million Btu. per hour, while the 26.3 value of furnace K represents 75 million Btu. of fuel burner per hour. The smaller furnace has much larger relative combustion volume and firing equipment than the larger unit which is further indicated by the much greater fuel rate. Production rate is a prime function of fuel consuming capacity.

The second criticism stated that the P factor does not show the effect of over or undercharging. I think that it does in accordance with the following example: Assume that a given furnace taps its nominal capacity of 150 tons in 10.75 hr. The P of this operation is 20.0 or the furnace is actually making 13.96 tons per hr. The furnace is now overcharged so that it taps say 165 tons at 13.96 tons per hr. or in 11.8 hr. P under this condition is 18.2 tons which at once indicates the overcharged furnace, as a steel refining unit, is actually operating about 9 per cent slower than the furnace at normal rating.

Should the same furnace be charged to tap 135 tons and make the heat at the same rate of 13.96 tons per hr., the heat time is 9.67 hours and $P = 22.5$ tons which is 11 per cent faster than the base rate.

All of the above pre-supposes that fuel input per time unit remains the same as well as all other principal operating conditions.

It is thought the foregoing will serve to indicate, that with all the necessary data at hand relative to campaign life, the principal items of the cost above, the actual production and fuel records, etc. there is a basis presented in the P value, through which the optimum production rate of any unit can be found.

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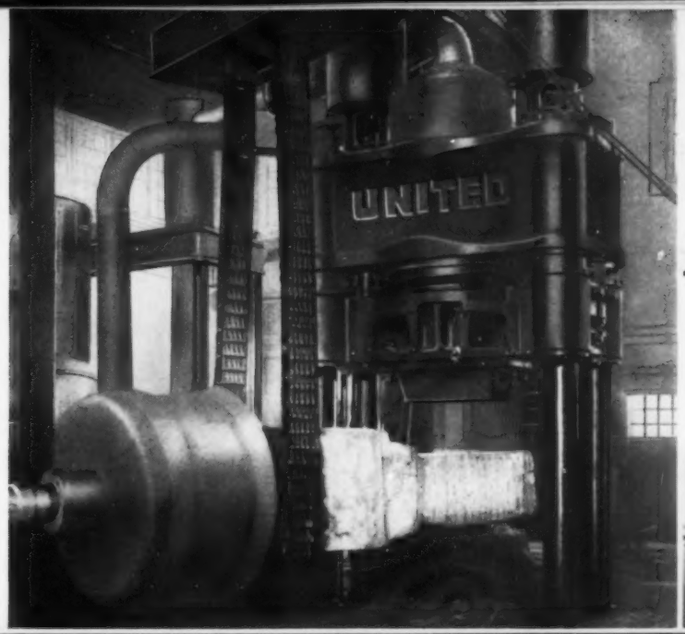
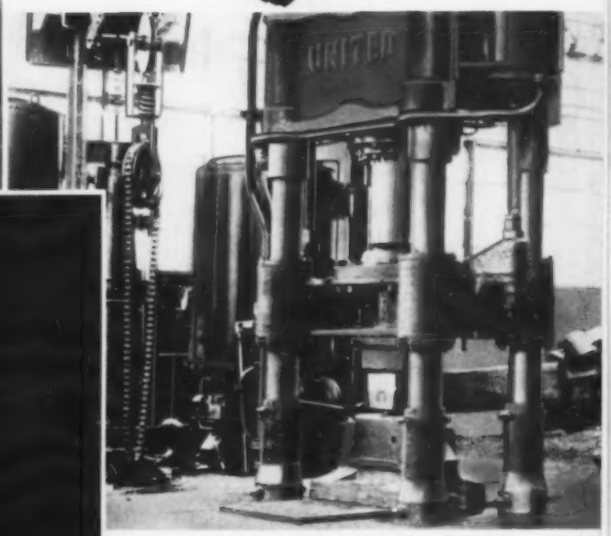
ENGIN

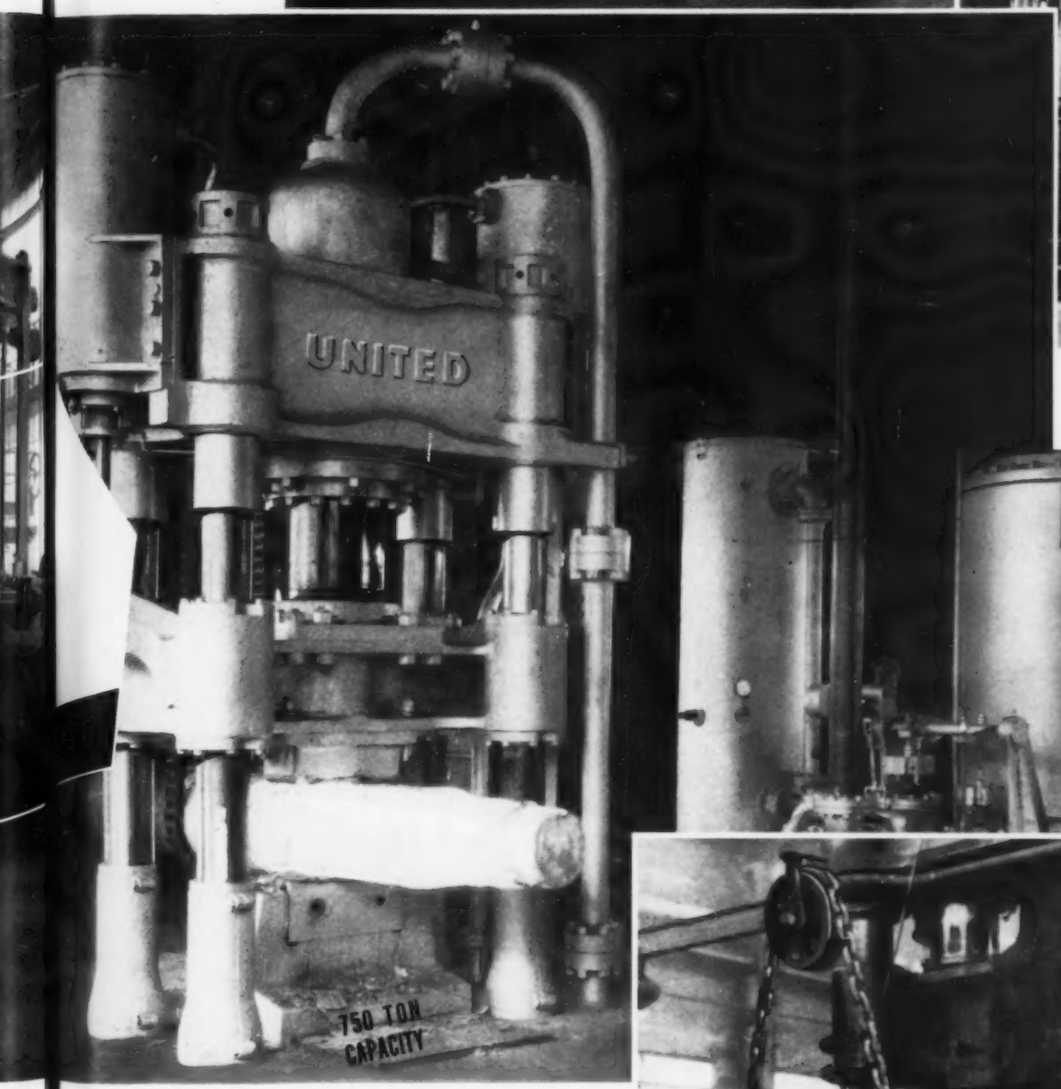
PITTS



1200 TON CAPACITY

1000 TON CAPACITY





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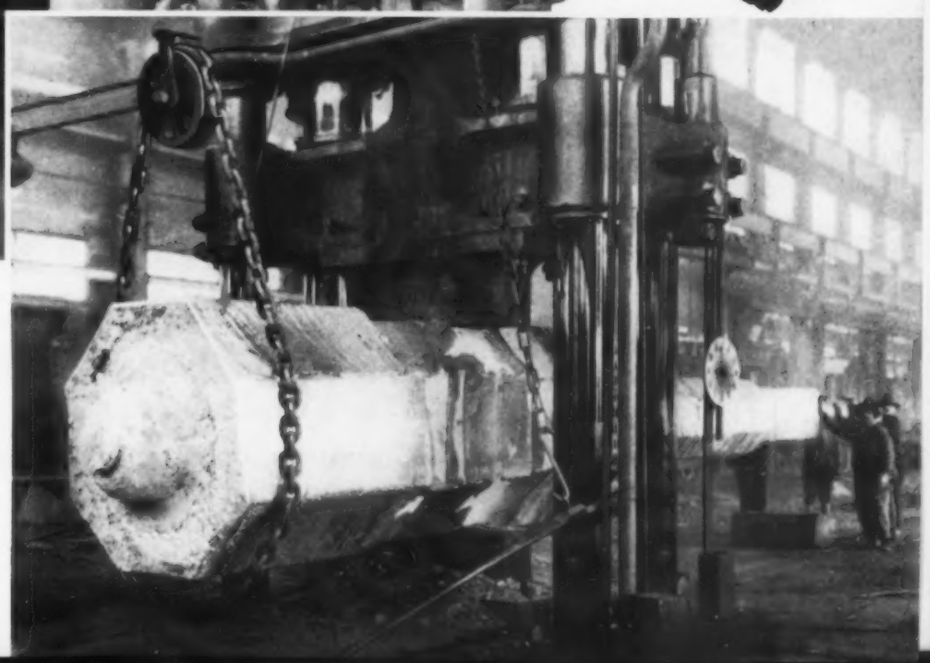

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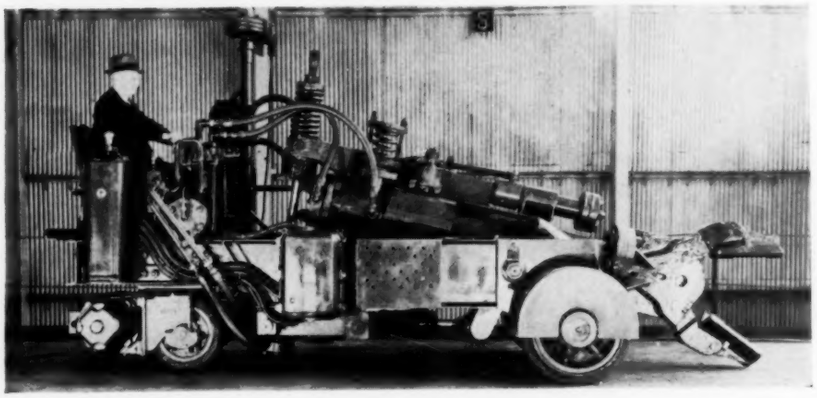

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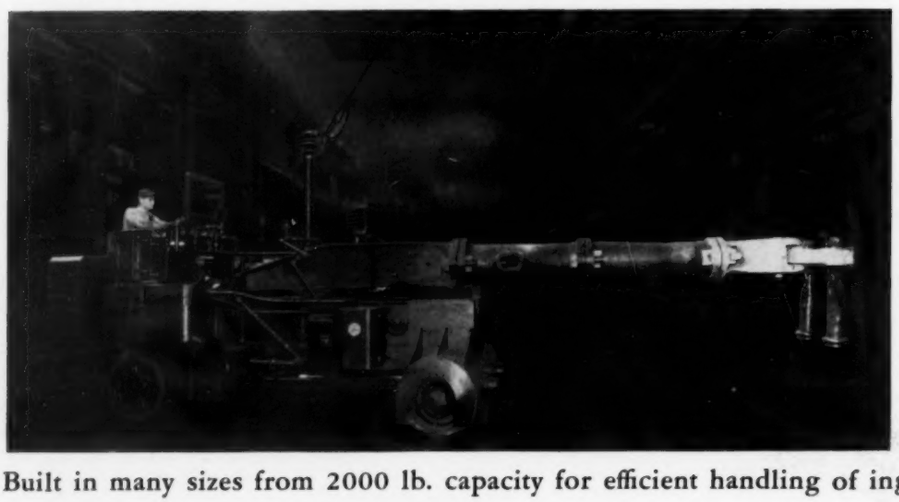

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DEVELOPMENT...

in Forging Practice

By J. L. YOUNG and J. J. ANDRA
United Engineering and Foundry Co.
Pittsburgh, Pennsylvania

Presented before A. I. S. E.
PITTSBURGH DISTRICT SECTION
November 18, 1940

▲ IT has been stated that the metals are the physical sinews of modern civilization. This statement is no doubt true, realizing the extensive use of metals (particularly iron and steel and the non-ferrous group including aluminum) in the manufacture of tools, machines, automobiles, ships, aircraft, buildings, munitions, etc. One of the most important properties of metals is that of plasticity or their ability to be permanently changed in shape without rupture. This property allows us to carry out one of the most important operations in the manufacture of the many articles made from metal, namely that of forging.

Forging is the art of forming or shaping metal by heating and hammering or pressing. It is sometimes called the "mechanical treatment of steel," because if properly carried out, forging not only produces the correct shape, but improves the structure and physical characteristics of the steel. There are four main factors that can be affected by forging practice: (1) changing the total analysis; (2) changing the distribution of ingredients; (3) change of grain size and shape; (4) introducing internal stresses and strains. A further explanation of these four factors follows.

Changing the total analysis. Formation of scale (iron oxide) and more or less decarburization always takes place during hot forging operations. Decarburization is the result of an oxidizing atmosphere leaving a skin low in carbon in the steel which is subsequently removed during the machining operations.

Change of distribution of ingredients. Hot working produces a more homogeneous structure, and develops lines of flow or fiber, especially when the piece is upset. It also may produce a change in the relative segregation present in a cast steel ingot, and the effect is comparable to the effect produced by kneading dough. The kneading of dough produces a better distribution of the ingredients; a similar action occurs when steel is hot forged.

Change of grain size and shape. Coarse-grained ingo castings are changed into fine-grained forgings by mechanical working. The grain size of a forging plays an important part in its physical behavior. For best results the grain size should be a minimum for a given hardness, and knowing that hot forgings will cause a rebirth of the grain structure, by proper control the structure of very coarse-grained ingot castings can be refined. The initial structure, the amount of working, the temperature of the heats, and the finishing temperature, determine the degree of refinement expected in hot forged objects.

Introducing internal stresses and strains. Cold working produces marked internal stresses and causes marked distortion of the structure of steel, changing the grains from a symmetrical shape to an elongated shape. It also increases the hardness and tensile strength, but reduces the ductility or plasticity of the metal, and if carried out far enough it produces brittleness and failure of the metal by rupture.

The art of forging is undoubtedly the oldest of the mechanical arts of metal working, yet less has been written on this subject than on any of the other phases of metal working. It is with this thought that we propose to tell briefly the story of the many centuries of forging, and to outline the development of this industry and its equipment. Let us for a moment go back into history and trace this industry from its origin.

The background of the forging of metal reaches as far back as civilization itself, and practically every historic record gives evidence of the importance the forging of metal held in the life of every people of every era. Museums are replete with forged articles which are indisputable evidence of the superb workmanship of the ancients despite their lack of equipment, and they offer visible proof that the forger has been at work throughout the years in a very commendable manner.

Just when and where the art of forging came into use,

history is not able to define very clearly. It can possibly be deduced from the bits of facts gleaned from legends, records, and relics that the forging art was long in use before there existed written records. It is surprising to find in our available records that the hydraulic press antedates any of the mechanical presses in use or known to the early engineers, except possibly the screw press as used in printing by Caxton as far back as 1456, or even earlier.

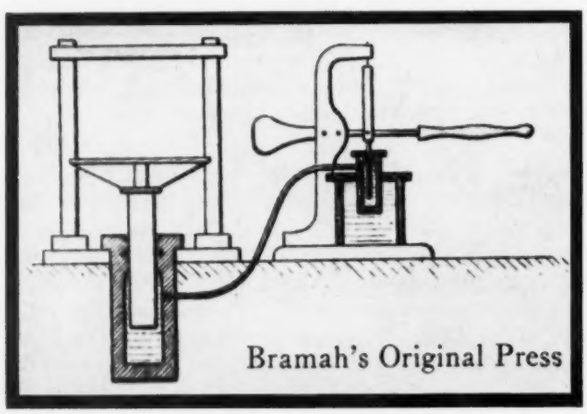
We find in some of the Seventeenth century works of Pascal, a mention of the hydraulic press. It was about 1638 that Pascal spoke of the press, but it was not until Jos. Bramah invented the cup leather and built the press shown in Figure 1, that any practical use was made of the machine, as heretofore, it was impossible to hold the water pressure between the ram and the cylinder. The patent on this cup leather was dated 1796, and was very similar to cup leathers as used today. A 50-ton hydraulic press was built about that time for baling cotton and in general it was not far different from the basic designs of today.

Iron was doubtlessly used first in western Asia, the birthplace of the human race, although history indicates that copper, gold and silver were used before iron. Peoples in the early times despite their limited metallurgical knowledge and means for mechanical working of metal had visions of better meterials and more powerful forging equipment. There is no doubt that the ancient forges were crude affairs, and the mechanical appliances awkward, clumsy and slow, yet the skill of these artisans was such that the visible results arouse the warmest admiration today.

Most records of the past civilization indicate that the forge man has always held a leading position in the affairs of the nations, for upon his art depended the very lives of these countries since his products were the weapons that defended the people against their enemies, and so it is today.

All crafts in the early days were shrouded in secrecy and mystery whereby the knowledge of any art was passed from father to son or to the nearest male relative, thus making progress very slow and new developments few and far between.

Figure 1—Schematic diagram of an early hydraulic press, built late in the eighteenth century.



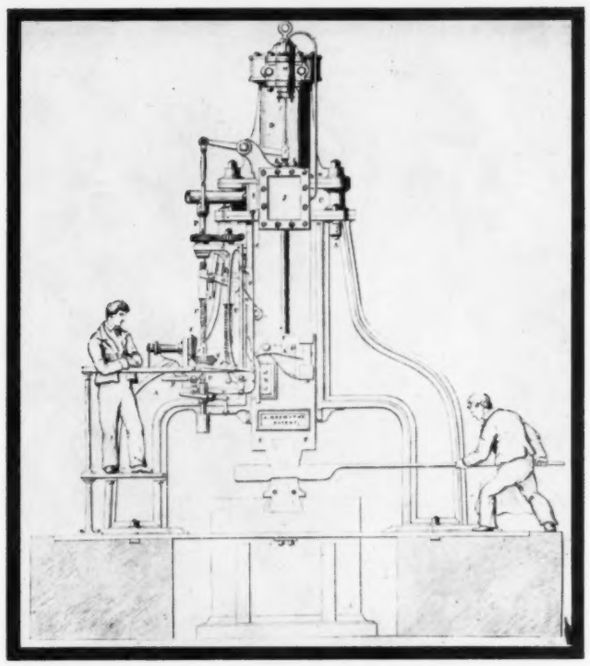


Figure 2—The Nasmyth hammer, shown here, is said to be the first direct acting steam hammer.

India appears to have been acquainted with iron and steel from an early age, and the welded iron pillar at Delhi holds evidence of that. The marvelously forged Damascus and Toledo swords possess a fame which reaches through the present day. Tradition relates that these swords were laboriously hammered, requiring an almost endless amount of work, in that the pieces of iron were hammered out, doubled over and welded at the forge until they resembled the color of the moon, when the blade was quenched by driving it into the thigh and leg of a slave. Slaves were plentiful but a good sword was an article of value.

It is evident that from the early ages through the dark ages the principal use of forging was to manufacture implements of war, *i. e.* swords, armor, helmets, etc. The thirteenth century witnessed the introduction of gunpowder and this brought about a complete change in the manufacture of iron and the art of forging. The old style weapons of war became obsolete and firearms replaced them. This change created a necessity for larger forgings and a need for better means of operation; it was now necessary to find means other than manual for the forging of iron and steel. While various means were employed to build mechanical hammers, the most generally used were the water hammers, where weights were raised by water wheels. The hammer or ram would weigh from less than one hundred pounds to nearly one thousand pounds. Such hammers were installed before 1742 in New Jersey by the predecessors of the Taylor Wharton Iron and Steel Company. These hammers weighed from 400 to 600 pounds each. The iron was first hammered lightly under hand sledges to force out some of the slag, then it was reheated and

forged under the heavy waterwheel hammer into short thick squares, reheated and then finished under the waterwheel hammer.

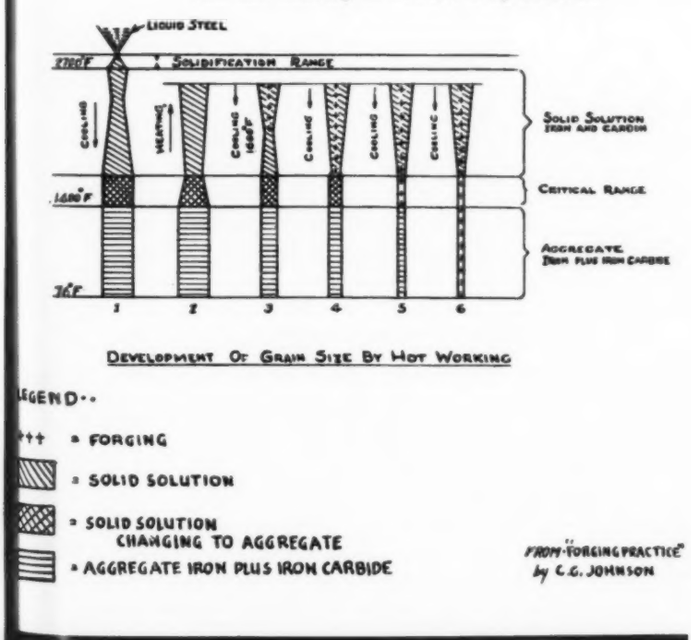
Up to the nineteenth century very little change had been made in the design of power hammers excepting possibly for size, and no other forging method was in use. During the nineteenth century the use of steam for power grew and forced its way into industrial use through the development of the steam engine. Attention was turned to the problem of making use of this new type of power to operate power hammers, and the result was the development of a power hammer where the helve was raised by means of a cam operated by a steam engine.

About this time a French machine was developed, using steam to develop the power instead of water, but it was apparently used for punching instead of forging.

It was in 1838 that James Nasmyth, a Scottish engineer, conceived the idea and developed plans for the first direct acting steam hammer, as a necessity to forge the crankshaft for the steamer *Great Eastern* at Trafford Park, Manchester, England. This hammer was not built until some years later by French business men, and in 1848 Nasmyth received patents on his design. The development of this direct acting unit made available the means of making forgings of considerable size, but now it was difficult to obtain ingots of sufficient size. This difficulty was overcome by Frederich Krupp, of Essen, Germany, who exhibited an ingot of 2¼ tons at the International Exhibit at London in 1851.

The original Nasmyth hammer shipped to the United States for the Taylor Wharton Iron and Steel Company of High Bridge, New Jersey, is now on exhibit at the Museum of Commerce and Industry, Chicago, Illinois.

Figure 3—Chart showing the relation between grain size and hot working at various temperatures.



About this time came the demand for larger and stronger guns than the cast iron ones in use, as well as for tougher armaments than could be obtained by the use of wrought iron. This created the necessity for steel that was cheaper than was obtainable by the crucible process, and in 1856 Henry Bessemer gave the world the bessemer process for making steel, which changed the picture of the industry, for now there was no difficulty in making large ingots. It might be pointed out that up to the adoption of the bessemer steel-making process, there seemed to be a continuous struggle to either get the hammers large enough for the metal size, or to obtain the metal sufficiently large for the capacity of the forging equipment.

In 1862 patents were granted for what is generally considered the first drop hammer, the patents going to two men then living in New England. After the war between the states, a few forging plants began to make their appearance. In addition to firearms and war materials, forgings began to find use in the machinery building field. It may be seen that the hammer was the first piece of forging equipment and its development extended through the ages.

The development of the mechanical and hydraulic forging press is quite as interesting and is a repetition of the hammer story. The printing press is probably the first real start of the press for commercial purposes and through the years more uses were found as the presses emerged from the crude clumsy affairs to our variety of modern presses for every press service. The screw press found earliest use in stamping of coins and medals, and later came the hydraulic press and the crank press. As the materials for building presses became better, and casting and forging technique improved, the size and pressures increased, which in turn developed a greater variety of work for presses. Up to the twentieth century forgings found most of their use in the machinery building industry. The advent of the automobile multiplied by many times the demand for forgings, for automotive engineers realized very quickly that the development of their industry depended upon these inherent qualities found only in forgings. It is evident that the motor car of today could not have been produced in quantity and quality without the liberal use of forgings.

The present century has seen the real growth of the forging industry. In 1899 the value added by manufacture for concerns primarily engaged in the production of commercial forgings was slightly over $5,000,000 while in 1929 this figure had grown to over $200,000,000. It is interesting to note that while all of the forging equipment was first developed in the New England section, the greatest percentage of the forging tonnage is now produced in the area bounded by New Jersey on the east, Chicago on the west and Detroit on the north.

The primitive tools of the ancient smith have changed into mechanical wonders, and the mythical hammer of Thor has turned to reality in the massive and powerful forging equipment of our present day. The old stone or wrought iron hammer is now a steam or motor driven unit, and the relatively light weights lifted by the waterwheels have been supplanted by rams weighing up to 40,000 or 50,000 lb. in the large drop hammers, and approximately 1,300,000 lb. in a modern 14,000 ton

hydraulic forging press. (Weight includes ram, crosshead, die and other moving parts.) The puny squeeze offered by the early printing or coining press has been supplanted by modern forging presses that squeeze ingots weighing many tons.

Today, with a wealth of ultra-modern equipment at our command, coupled with the vast amount of knowledge gained through research, study can be made of the changes that take place within the metal being worked, and thus it can be determined why certain physical changes occur. The ancients knew "how" but not "why." Today, not only how is known, but also why, and the results produced by forging can be controlled not only as to shape, but also as to structure and physical properties of the finished forgings.

It is a long step from the forging methods employed by the ancients, to the machine methods used by modern manufacturers. The forging industry has grown from the simple hammering methods to many methods and different practices.

The industry, as it is known today, makes use of various types of forging equipment for the practical duplication of forged parts for commercial service. Such forging equipment includes the drop hammer, the trip and helve hammer, the forging machine (upsetter), the forging hammer, and the mechanical and hydraulic forging press.

Forging presses are used extensively for a variety of forging work, and there is no doubt that their field of activity is extending very rapidly.

Mechanical forging presses may be of the single acting or double acting type. The single acting press operates in a similar manner to the cold working press, where the guided ram is moved downward. Such presses are used on work requiring one or more forging steps but

Figure 4—Four columns, with separate intensifier and prefiller, mark the design of presses over 500 tons in capacity.

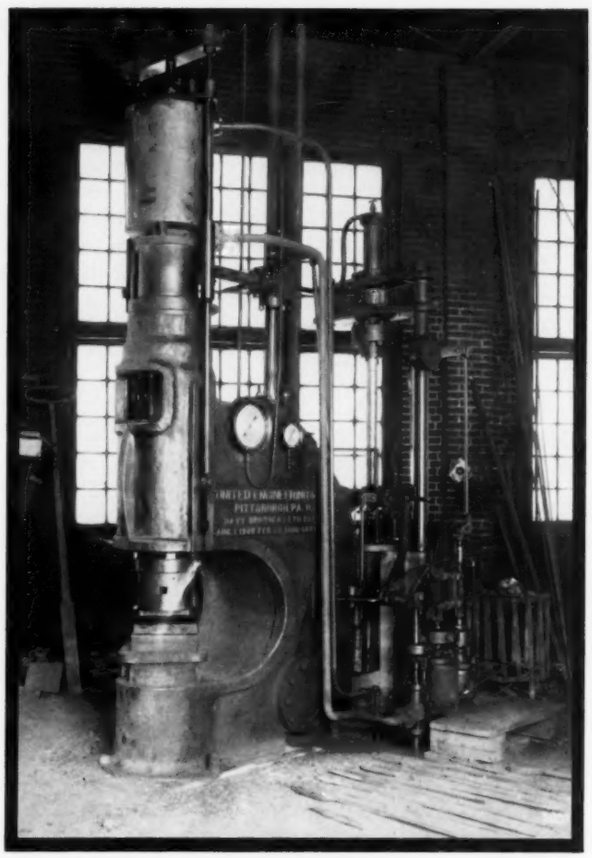


Figure 5—This 150/300 ton open frame steam hydraulic forging press employs its hollow frame as the prefill chamber.

are somewhat limited in the scope of their forging work. The double acting press has, in addition to the stroke, a second motion whereby the dies can be made in two parts and moved together during the stroke operation. Virtually, the double acting press may be considered as a vertical forging machine, and it operates in a similar manner.

The horizontal mechanical forging machine, or upsetter has come into general use in the last fifteen years. Here again the automotive industry has played an important part in the development and many complicated sections of both hollow forgings and queer shapes have been made successfully at high rates of production, and at very close tolerances. The latest use of this process is the making of shell forgings.

HYDRAULIC FORGING PRESS VS. STEAM HAMMER

The modern hydraulic forging presses, operated by air hydraulic, steam hydraulic or straight hydraulic systems, are made in sizes ranging from 150 to 15,000 tons. The range of work of this type of press is far beyond that of the largest steam hammer; while the class of work in some respects is the same, the principal difference is that the steam hammer moves the metal by impact pressure, while the hydraulic forging press imparts squeeze pressure to the metal.

The hydraulic press is used in the reduction of all large ingots for which use it possesses certain advantages over the hammer. Two of these advantages are: First, that the full capacity pressure can be applied without respect of the ram travel; second, the load or pressure is slowly applied to the work, thereby promoting deeper and more permanent effect. The somewhat loose texture of the core of very large ingots can be materially condensed by the "kneading" action of the press.

The potential energy of a steam hammer on the other hand is greatly reduced by a restriction of the piston travel, and its effective efficiency is correspondingly reduced. The high velocity with which a blow is delivered also tends to forge the metal at the surface only, leaving the core unaffected. The greater the velocity of impact, the greater is the energy required to effect a given deformation.

The slow application of pressure of the hydraulic press enables a small press to make forgings of a size that would require an enormous hammer, and results in deeper penetration of the beneficial effects of forging, so that the center of a large forging is better worked by a press than a hammer. The comparison between the hydraulic forging press and the steam hammer to determine, in a general way, the approximate equivalent size of a steam hammer for a given size of hydraulic press, can be made by the approximate size of ingot forged by the respective units. The following table makes a general comparison:

Rated size of hydraulic forging press, tons	Approximate maximum ingot size, in.	Rated size of steam hammer, lb.
300	12	3000
500	16	5000
750	24	10000
1000	30	16000
1500	40	25000
2000	48	50000
3000	60	.....
4000	64	.....
5000	70	.....

The general impression among the users of both types of equipment seems to be that for the smaller commercial forgings up to about the capacity of a three thousand pound steam hammer or a three hundred ton forging press that the hammer tends to produce faster and more economically. However, in sizes over this capacity, the trend appears to favor the forging press except in cases of such special forgings as shell forgings.

Steam hammers of the larger sizes have been largely replaced by the high speed hydraulic press, principally because of the great superiority of the press over the steam hammer, not only in respect to production, which is about double that of the steam hammer of similar rated capacity, but also because of the more sound forgings that can be produced.

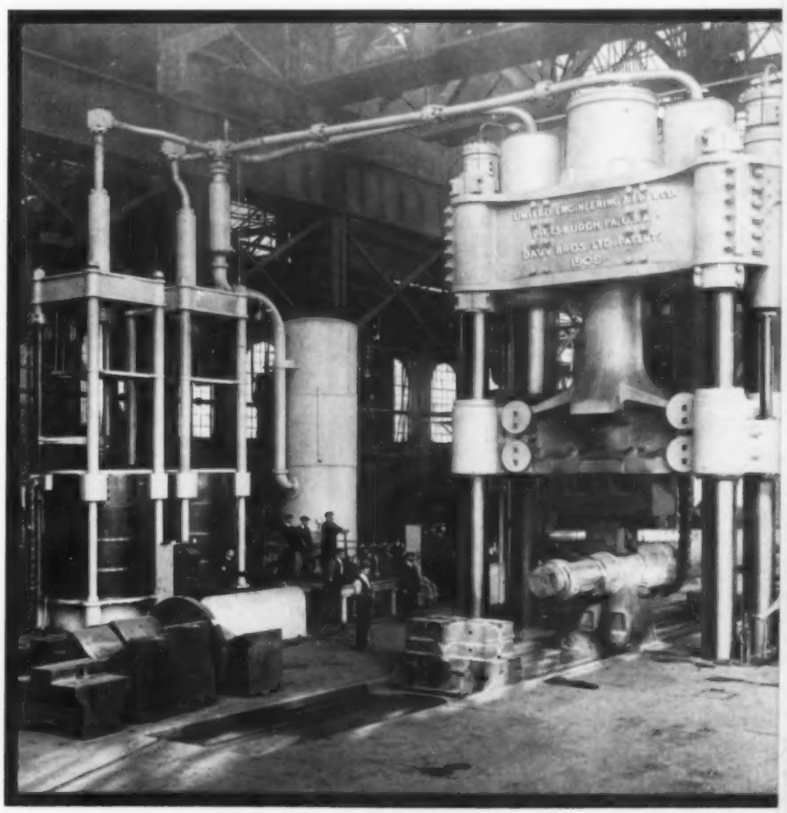
As an instance of the production obtainable with a modern quick-acting press, a 2000 ton hydraulic press of the intensifier type, starting with a 45 in. ingot, cogged down and finished a thirty foot length of 15 in. diameter shaft in one heat, using only flat tools. With a hammer of equivalent power, this work would have required not less than three heats. The great saving in time and cost of machining a forging made under a press, compared to a forging made under the hammer is an additional advantage favoring the press.

Another important advantage is that the high speed forging press can be operated with less steam consumption than a hammer for an equal tonnage of forgings. This, in addition to the great savings in repairs and upkeep, due to the absence of heavy shocks and vibrations, is a large item in the general operating cost. While the initial cost of the high speed forging press is somewhat more than that of a steam hammer of equal forging capacity, it must be borne in mind that the press, being entirely self-contained and without jar requires a much lighter foundation. The hammer must have a massive substantial foundation under the anvil block, thus reducing appreciably the total difference in installation cost between press and hammer.

The press with its silent working and absence of vibration contrasts very favorably with the hammer which often causes considerable detriment to adjacent furnaces and any machine tools in the vicinity.

The advantage of the press is recognized by government requirements for forgings, which stipulate that

Figure 6—This 6000 ton steam hydraulic press is equipped with hydraulic mandrel gear and motor-operated turning block.



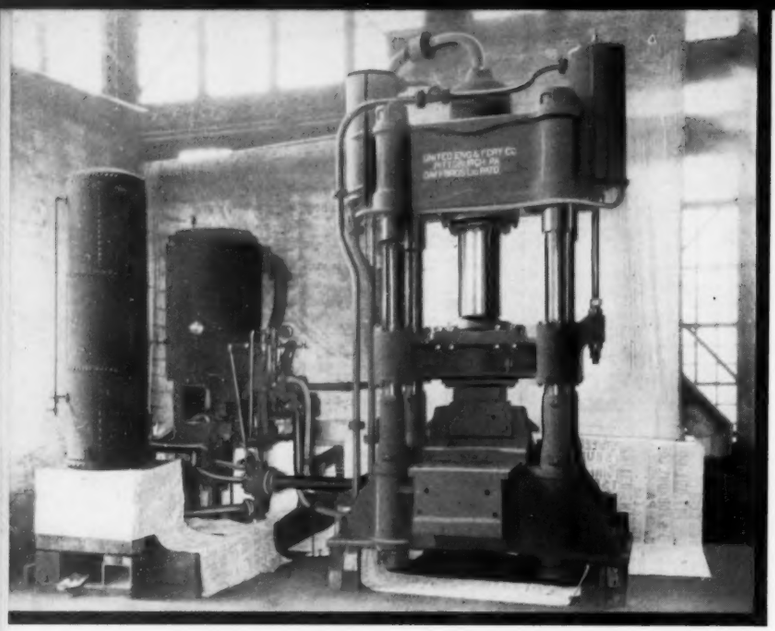


Figure 7—A typical steam hydraulic press, showing intensifier and prefill tank with piping and valves.

for rolled or hammered steel, the ingot must have an initial section eight times the finished section, whereas those pressed need have only four times the finished section.

STEAM HYDRAULIC FORGING PRESS

This press is a development of the hydraulic press combined with steam as the basic medium for intensification of pressure and rapidity of stroke, and is built to increase forging production. The high speed type of forging press includes all the refinements and best features in this class of machinery, and is recognized both in this country and around the world.

The hydraulic forging press receives its pressure through the medium of some fluid, either oil or water. Pressure is imparted to the fluid by means of pistons which are actuated by steam pressure, compressed air or water. Where water is used, the pressure is obtained through motor driven pumps. The hydraulic pressure is delivered to a cylinder from pumps or accumulator, or from a steam hydraulic intensifier, or air hydraulic intensifier, which increases the low working pressure of 90 to 200 lb. per sq. in. to a hydraulic pressure of about 6000 lb. per sq. in. This hydraulic pressure cylinder is mounted below the steam cylinder alongside the press. The operating principles of pump driven, steam driven, or air driven presses are alike.

The larger size presses, including 500 tons and upward, are of the four-column type, with the intensifier and prefiller being separate units as shown in Figure 4. The 150 ton and 300 ton sizes are of the open or C-frame type, with the hollow frame serving as the prefill chamber, as shown in Figure 5.

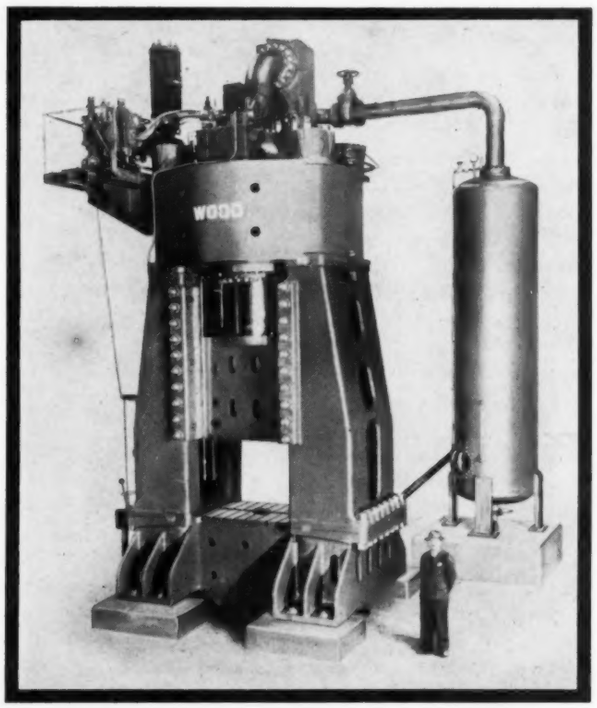
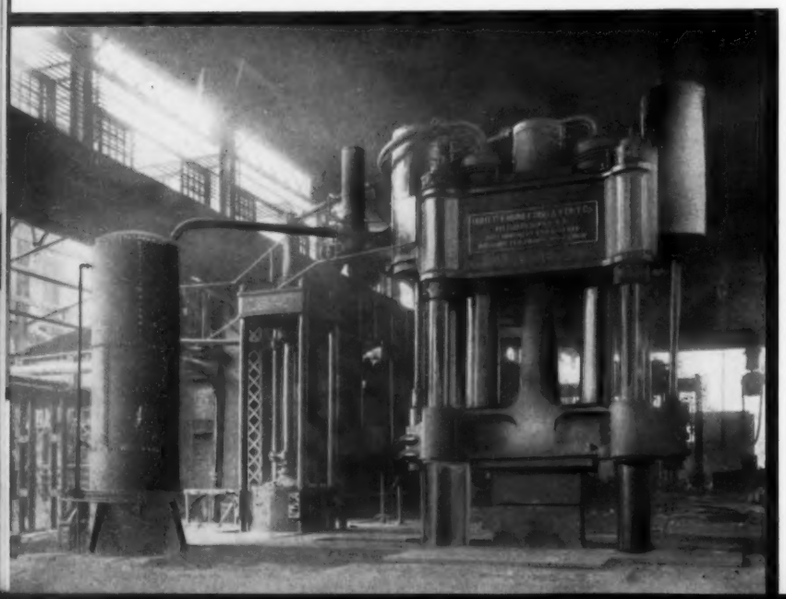


Figure 9—This 3000 ton pure hydraulic press operates from a 4500 lb. per sq. in. pneumatic accumulator system.

Figure 8—Two operating cylinders with center stock arrangement are used in this 2000 ton steam hydraulic press.



Presses of 2000 tons or more are furnished with double hydraulic cylinders, the guides for the press head being entirely independent of the main hydraulic cylinders. Additional and special equipment for such presses can be furnished, such as a device for manipulating the mandrel or ingot, or a hydraulic mechanism arranged laterally with the press for changing the dies, or motor operated turning blocks.

Large presses also have two lifting cylinders in which steam or hydraulic pressure gives a very rapid lift for the return stroke, rods from the pistons being connected to the press head.

A prefiller charges the main cylinder with low pressure water, the full hydraulic force coming on when the top tool touches the work.

The control of the intensifier or forging stroke is attained by means of a single lever control gear, which operates to close the steam valve at a point of the intensifier stroke corresponding to the position of the hand lever. The movement of the press head follows exactly the operator's hand, both as to speed and length of stroke, thus, a slow movement of the hand lever results in a correspondingly slow squeeze of the press, and stopping the movement of the lever arrests the action of the press. This gives the operator complete control of the action of the machine, a valuable feature when cutting off or when a bending operation is being performed.

Many hydraulic forging presses are built to individual requirements where the working stroke may be varied to suit special conditions, such as some large presses now under construction where the off-center load is as much as six feet from the centerline of the press for the full press capacity.

PRODUCTION

From a standpoint of production of the standard steam hydraulic forging press, octagon ingots measuring 188 in. across and weighing 485,000 lb. are successfully forged under such presses. Although presses are not well adapted to form thin sections, they are admirably suited to upsetting, punching and trepanning large pieces, and for drawing long drums.

Trepanning is the operation of removing the core of an ingot, which is then worked over a mandrel into a hollow forging, thereby forming a hollow cylinder for such uses as boiler drums, gun tubes and backup roll sleeves. The object is to secure better working of the metal than would be possible in the case of a solid forged section.

Among the large forgings produced by such presses are large guns, boiler drum forgings, shafts, crankshafts, armor plate, marine forgings, turbine and propulsion forgings, die blocks, etc.

The finishing temperature of the large press forgings should be as low as practicable, for high physical properties are more difficult to obtain in large forgings than in small forgings.

One of the really difficult factors to consider in forging practice is that of production on the forging unit. In some branches of the metal working industry, it is possible to prepare tables of pieces per hour, cutting feet per minute, tons per hour and data of similar nature. In forging practice, production is dependent upon many variables and a change in one or more has some influence on the possible production of any forging. Such variables will include the weight and design of the forging, type and value of material, design of the forging dies, permissible forging tolerances, type of heating equipment, method of handling, and the skill of the forging crew.

MISCELLANEOUS PRESSES

The pure hydraulic side frame type press rated at 3000 tons, and shown in Figure 9, operates from an air bottle accumulator system, working at 4500 lb. per sq. in. The tank on the right is a prefill tank operated

TABLE I

CHARACTERISTICS OF COMMON METALS WITH THEIR ANNEALING AND HOT WORKING TEMPERATURES.

Metal	Workability at room temperature	Lowest recrystallization temperature after severe cold working, degrees F.	Usual annealing temperature range after cold working, degrees F.	Usual hot working temperature range, degrees F.
Aluminum	Very good	300	650	600–900
Brass	Very good	400	1000–1250	1100–1650
Bronze	Fair	750	1000–1250	1100–1650
Copper	Very good	400	1000–1400	800–1900
Duralumin	Good	500	640–670	600–850
Gold	Excellent	390	500–1000	Room temperature
Iron	Good	840	1100–1400	1500–2400
Lead	Excellent	Below room temperature	Anneals itself	Room temperature
Monel metal	Fair	800	1350–1450 in box	1600–2100
Nickel	Fair	1110	1100–1750	1600–2300
Steel, structural	Fair	900	1100–1400	1500–2200
Steel, high carbon	Poor	1000	1100–1400	1400–2000
Silver	Excellent	390	500–1000	Room temperature
Tin	Excellent	Below room temperature	Anneals itself	Room temperature
Tungsten	Poor	2190	2200–2500	1100–2900
Wrought iron	Poor	900	Not cold worked	1650–2450

at about 70 lb. pressure. This press is controlled from a single lever through the prefill and full pressure stroke, and return.

Other special presses of recent design are those of the piercing type for making shells. A recent development is the inverted pot type of piercing unit that is used as the first step of a two-step operation, the second step being the roller draw press, or the three-cross-roll mill for elongating and sizing the pierced billet to make the finished shell forging. The piercing press is of the pure hydraulic type, using water or oil as the fluid. The hydraulic pressure is developed (up to 2500 lb. per sq. in.) by either rotary, centrifugal, or reciprocating pumps, and a weighted or air bottle type accumulator.

The main cylinder is of the double acting, inside packed type, mounted centrally between three columns. One of these columns is used as the center for a turret upon which four punches are mounted. The turret is actuated by a hydraulic cylinder and is locked by a wedge, which in turn is actuated by another small cylinder. All of the mechanism is interlocked so that the press becomes a semi-automatic unit controlled from two levers.

The shell billets may be deposited in one position of the turret on the stool directly under the punch. At the next operation, this turret is indexed 90 degrees to the piercing position. The billet is then pierced and at the next operation is indexed 90 degrees further around the circle to the discharge position. At the fourth position, arrangement has been provided for quick changing of punches. During all of this time the punches can be cooled by water sprays.

Another recent development is the "one shot" shell forging press. Complete shell forgings are made in one operation in this new machine.

DISCUSSION

PRESENTED BY

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J. A. SUCCOP: The authors have given a very enlightening description of the history of the development of forging practice, and have also given a very capable explanation of the mechanics of the forging hammer and forging press.

I would rather give a brief description of the metallurgical aspect of what happens to a piece of steel when it is forged under a press or a hammer, than comment directly on the paper.

As explained, the press and the hammer are not identical tools, for the hammer hits an impact blow and consequently the surface metal flows, whereas the press delivers a static blow and the pressure is on the metal sufficiently long for not only the surface metal to flow, but also the metal from the surface to the center. The press and the hammer have each found a very definite place in the forging industry and the following is a very brief description of the advantages of one compared with the other.

The advantages of the press over the hammer are:

1. Larger mass can be shaped or formed.
2. Absence of shock and vibration which is beneficial to the machine and the material being worked.
3. Lower cost, especially for large masses, due to greater production.
4. Due to the slow plastic flow of the metal, the effect of the press is felt to a greater depth than from the hammer.
5. Less fuel consumption per unit weight.
6. A higher output-power ratio, that is, a much greater proportion of the work put into the press is transmitted to the metal; much of the energy of the hammer is dissipated in the spring of the anvil and in vibration.

The advantages of the hammer over the press are:

1. Forges closer to dimensions.
2. Surface of finished work is more uniform.
3. Grain structure of surface regions are more refined.
4. Fiber structure less distorted, which may, or may not be an advantage. However, the reduction, coupled with subsequent heat treatment, leaves little preference in the structure of steel either hammered or pressed, providing the proper size selection of equipment has been made.

It would be hardly possible to intelligently discuss hot working of steel without interjecting a word or so regarding the proper heating of the raw ingot or its semi-finished product at any time of its stage of conversion into finished forged products. The heating cycle and method of heating are equal in importance to any stage of the fabrication of the steel. The rate of heating requires careful consideration, especially the raw ingot, which is particularly tender, due to its coarse crystalline

structure and open texture. The heating should be uniform and gradual, at a rate not too rapid, to insure against excessive temperature differences between the center portion and the surface which may cause fissuring and cracking of the steel.

The coefficient of expansion of steel is roughly .000007 per degrees F., within a range of 32 to 212 degrees F., and increases with increased temperature. Above 1600 degrees F., it is approximately .000016. To exaggerate conditions, let us assume a steel ingot 40 in. square by 80 in. in length, was heated at a rate which resulted in a condition of 2200 degrees F., at the surface, and 1600 degrees F. at the center—a temperature differential of 600 degrees F.

Accordingly, the surface would expand transversely approximately 4 in. more than the interior. When we consider the length, instead of the cross section, the dimensional differential is still greater—approximately 8 in. greater than the interior. It is also possible to develop still greater differentials when portions of the same ingot or billet are within and without the transformation ranges.

It is difficult to conceive the enormous stress which would be required to produce the same effect mechanically. As the size of the ingot increases, the greater is the liability of stress differential. Thermal conduction is slow in highly alloyed steels, thus requiring extremely slow rates of heating.

It is generally thought that the old rule of one hour per inch of diameter still applies to the heating of steel. The speaker has personally witnessed masses of 30 in. to 40 in. in diameter of alloy steels (Ni-Cr-Mo type) broken into several transverse sections, attributed to too rapid heating; the breaks being as clean and smooth as if the sections had been cold sawed and usually at a distance from the end equal to the cross sectional dimension of the billet. Time of heating or holding at the forging temperature, especially of the structurally weak steel ingot, should be of sufficient duration to insure complete heat saturation of the interior, and then promptly forged or worked to avoid the condition of over-heating.

Over-heating results in an enlarged and relatively weak crystalline structure which will require considerable time and expense to correct by a special heat treatment, or by a combination of hot mechanical work and heat treatment. Actual heating time will depend on the type of steel, size, shape and the furnace equipment, the stern requirements being that the steel is thoroughly saturated to the center.

Maximum forging temperature is of utmost importance. In some cases, forging ranges are narrow and an intelligent knowledge of the temperature to start forging is essential. In order to render the steel plastic or readily workable under the hammer or press, it must be heated. The higher the temperature, the more freely the steel will flow under pressure. Therefore, the highest possible safe temperature is desirable.

Unfortunately, steel will "burn." That is, oxygen penetrates the crystalline network and forms non-metallic iron oxide in the crystal boundary lines, thus permanently weakening the cohesive capacity of the individual crystals beyond any commercial method of salvage short of re-melting.

Accordingly, forging temperatures, close to that actually required for properly working the steel, should be employed. Usually 200 to 300 degrees F. below the solidus line, which in the iron carbon equilibrium diagram marks the region of melting, is considered safe.

A few examples of heating are:

Type of steel	Maximum forging temperature, degrees F.
1.50 carbon	1900–1925
1.10 carbon	1965–1980
1.00 carbon	2000–2050
.90 carbon	2050–2100
.70 carbon	2150–2200
.60 carbon	2200–2250
.50 carbon	2275–2300
.40 carbon	2320
.30 carbon	2350
.20 carbon	2375
.10 carbon	2400
3 per cent nickel	2280
5 per cent nickel	2300
3 per cent nickel, 1.50 chromium	2280
Chromium-vanadium	2280
Stainless	2300

Furnace atmosphere is a factor too often taken for granted and held as an unavoidable evil associated with high temperature heating for forging. The maintenance of proper atmosphere, with slow soft flames, during the heating, tends to minimize the amount of surface decarburization and scaling. Excess oxygen should be excluded by employing proper equipment and efficient combustion.

Scaling, in poor heating practice, often amounts to 5 to 10 per cent loss in the steel, which, with corrected atmosphere, can be decreased to 3 to 5 per cent. It not only represents an economic loss of metal, but is responsible for many forging difficulties. If it is driven into the surface of the steel, it will cause machining difficulties and increase the cost of production.

Accordingly, reasonable application of heating fundamentals will react in the economy represented by higher quality products and in decreased cost of production.

Some consideration of the peculiarities of the ingot structure will not be out of place, since certain characteristics are impressed on the steel during solidification in the ingot mould. These are seldom entirely eliminated by any subsequent hot working or treatment.

In its molten state, steel is substantially a homogeneous liquid, composed primarily of iron in combination with carbon, manganese, sulphur, phosphorus and silicon. Special steels contain, in addition to varying percentages of alloy, nickel, chrome, molybdenum and other elements to give hardness, toughness, ductility and other properties.

During solidification, that is, during its transition from the molten to the solid state, the steel loses its homogeneity or uniformity and becomes a more or less heterogeneous mass. Other factors being equal, the amount of segregation increases with the size and

volume of the ingot. The larger the ingot, the more time required for solidification and segregation.

The elements primarily responsible for segregation are composed of carbon, phosphorus and sulphur, all of which solidify at lower temperature than pure iron. Manganese and silicon do not ordinarily segregate to any marked degree, nor do alloys such as chrome, nickel, vanadium, molybdenum and the like.

As soon as the liquid steel contacts the mould walls, it is chilled into a thin solid skin or shell, which is the beginning of selective freezing or solidification. From this shell, crystals, rich in the element which raises the freezing point of the alloy, begin to grow progressively inward and because of lateral interference with other crystals of similar character, they ultimately result in parallel, elongated or needle-like crystals, always at right angles to the mould wall. As solidification progresses toward the center of the ingot, another type of crystalline growth takes place in the core of the ingot, of very uniform distribution.

The inter-crystalline fillings, especially toward the core, are rich in these elements which lower the melting point of the alloy, and consequently, constitute the impure or weakening constituents, and collectively are termed "segregations." The size and proportion of the various crystal forms and the extent and location of the segregations depend upon the speed of freezing, which in turn, depends on the mass or sectional size of the ingot, pouring temperature, speed of pouring and the design of the mould. Further, where these several crystal structures abut against each other, there exist planes of weakness and these are usually further weakened by the stresses set up due to shrinkage after solidification. The inevitable sum total is a steel ingot known by any of its many descriptives—a tender, sensitive, fragile, coarse grained and highly stressed steel casting, which necessarily demands intelligent treatment in its subsequent fabrication into finished products.

Analysis shows that the initially formed chill crystals comprising the skin of the ingot are of practically the same analysis as the molten metal. Segregation begins almost immediately and persists at an increasing rate toward the center longitudinal axis of the ingot, being most pronounced in the molten mass which solidifies last. This accounts for the fact that the sinkhead or top crop portion of the big-end-up ingot is the most highly segregated part of the ingot, while in the big-end-down types, the greatest segregation is usually in the lower half of the ingot.

It is commonly held, except where creep value is of prime importance, that the most valuable physical qualities in steel are obtained where the metallographic structure exhibits a uniform grain character of smallest possible size.

It is evident then, that fine crystals are desirable in the ultimate structure of the hot worked piece reduced from the coarse grained ingot.

Hot mechanical working above the critical temperature of steel distorts each individual grain. This deformation is not permanent in the structure of the solid, but endeavors to resume its original form. However, it is hindered in this by the rigidity of the mass and consequently breaks up into a number of smaller grains possessing the characteristic form.

Since the refining action is confined to the areas directly under pressure, these reduced areas upon relief of the pressure, are again free to coarsen as long as the temperature is above the critical range. The transformation product, austenite or solid solution of carbon in iron, is free to shape and arrange its constituents in a form peculiar to their state of equilibrium.

Thus, the process becomes one of repeated changing structures, alternating between that of grain growth and grain disintegration or granulation.

To what extent the grain size will be reduced by the hot working operation will depend, therefore, on the amount and speed of working and the temperature at which the work ceases. In order to produce as fine a grain as possible in the austenite, the steel should be worked continuously down to a temperature just above its critical range where the austenite is just beginning to show grain growth.

To insure against a non-uniform grain size and an excessively irregular structure, some deformation should be done on all portions heated for each successive operation and the body should be reduced in diameter to some extent each time it is brought to a forging temperature. Likewise, the forging temperature, prior to each successive working, should be adjusted so that the finishing temperature is as nearly correct as possible.

However, it is no secret that in spite of the close control over the aforementioned facts, extremely large forgings will lack regularity of structure due to solidification faults and non-uniformity in the grain structure. In order to produce greater regularity throughout the forging, that it may respond readily to the usual normalizing and tempering or quenching tempering treatments, it is often necessary to first normalize the forging as much as 300–500 degrees F. above the critical range.

When cast crystalline structures of steel are hot worked, the crystals in a greatly reduced size, line themselves in a direction parallel to the direction of working and, in a fracture of the piece or a macro etch, give the appearance of a somewhat thread-like arrangement of fine crystals, termed "grain flow"—"crystal flow"—"mechanical flow lines," and more commonly "fiber."

The proportion of this fiber produced in a forging depends on the ratio of work from the ingot to the finished forging size, and necessarily influences the mechanical properties of the piece.

Researches on large steel ingots, subjected to various degrees of hot work, show that steel forgings, given a very large forging reduction from large ingots, have a certain weakness in a transverse direction, without materially affecting the axial or longitudinal strength.

In view of these statements, it is implied that the reduction of area from the ingot to the forging, by hot working, may serve to reduce in the longitudinal direction, the effects of defects in the ingot, but none of the imperfections will be eliminated, and their effect in the transverse direction will be increased.

A striking example of too great a reduction may be cited in the manufacture of an alloy steel shaft (body 8 in. diameter) forged with a flange at one end (20 in. in diameter).

An ingot, sufficiently large (approximately 34 in. diameter) to give a forging reduction of 3 to 1 on the 20 in. diameter flange, develops a reduction of approximately 12 to 1 on the body. After an oil quenching and tempering heat treatment, tensile tests showed the comparison of transverse and longitudinal values to be as follows:

	Flange 20 in. diameter		Body 8 in. diameter	
	Longitudinal	Transverse	Longitudinal	Transverse
Tensile strength, lb. per sq. in.	109,000	111,500	115,000	113,500
Elastic limit, lb. per sq. in.	74,500	73,250	90,500	89,750
Elongation, per cent	22.1	17.2	26.2	13.2
Reduction of area, per cent	48	38.4	64.5	30.1
Izod impact, ft.-lb.	48	19	72	21

This striking difference in transverse values may be explained by the fact that the fiber with its probable contamination with non-metallic materials is made to occupy an increasing area across the test specimens as the forging reduction is increased.

Experience has demonstrated that where transverse tests have to be taken in addition to longitudinal tests, since stress will probably be applied in service in the transverse or cross fiber direction, it then becomes necessary to keep the ratio of work to finished forging size, such that little or no elongation of the non-metallic matter, which is always present, even in the cleanest steel, takes place. The amount of work should be such that it does not interfere with the ductility of the steel in the transverse direction, such ductility being measured by elongation and contraction of area in the tension specimen.

W. J. PATTISON: It would seem to me it has been brought out quite clearly that the open hearth department has a great responsibility in making good forgings. If the open hearth makes poor steel, the finished forgings will be poor no matter how much attention is given to the control of the heating. It also seemed to be brought out that even if you have these fine presses and fine hammers, you also have to have good men to operate them. In line with the defense program, many thousands of dollars are being expended for forging equipment, but it is also necessary to have good men to operate this equipment which engineers are bringing forth.

From some of the remarks you might think the hammer is obsolete and is being superseded by the press, but I believe the hammer still does a good job, if it is strong enough to work the steel all the way through. I know there are many hammers around the steel mills which certainly do make forgings from which you get good service in the blooming mills and other places where you need good forgings.

M. FOURNIER: In our shop we do not have any presses, but we do make quite a lot of forgings, such as shapes, by heat treating, and most of them are made out of alloy steels. We find after they are forged that the most important thing is heat treating them. Hammers are not entirely out of date.

C. F. SEYLOR: I have seen a great many types of forging equipment in the past few weeks and the thing that strikes me particularly is that they all seem so different. Some of them have good points and some bad. I would like to know which is the best so we won't make a wrong decision in selecting them.

S. FINDLATER: As regards the caliber of man required to operate shell presses, I would like to say that a definite contribution has been made in the design of the modern presses. The valving of the press may be so arranged that the importance of the human element in the operation of the press is diminished. This has been accomplished by coordinating the control of the various cylinders in a single operating lever so that each of the operations comes about in the proper sequence and at the proper time, and the press automatically resets for the next operation.

C. C. LEVY: I was very much interested in the discussion on the heat treating necessary for forging. The speaker mentioned the rate of heating and that the time of heating these billets is very carefully coordinated with the production of the press. In that respect it would seem to me that a method of heating by which you could carefully coordinate the production of the press would be of great advantage, and that no doubt accounts for the use of induction heating in some of these applications for forging shells. Another point in which the use of induction heating is important is in the nosing of the shells where the heat must not only be controlled as to time, but as to extent of the heating. In other words, the billet has to be heated just so far and with so much gradient of temperature, and that also would seem to be another reason why induction heating has become so active in this field of heating for forging.

J. L. YOUNG: I understand that from 2½ to 3 minutes are required to heat the end of a shell by induction heating in preparation for nosing. I have heard a number of discussions pro and con as to the advisability of induction heating. The principal impression seems to be that the installation is quite expensive but the unit cost for heating after the installation has been amortized is rather low, and there is an excellent control obtained through induction heating that is not as easy in gas or oil fired furnaces, and furthermore the scale problem is completely eliminated. Those who have gone to induction heating seem to easily justify the original expenditure on this basis.

From a standpoint of gas heating for nosing, I saw an interesting unit, which a company has developed. The unit is of the rotary type with the heating pot mounted like spokes of a wheel into which the shells are placed from the outside. From experience they have found that it is necessary to mount the hearth eccentric to the retaining pots in order to diffuse the heat slightly at the juncture of the heated and cold portions of the forging in order to prevent upsetting or bulging during the nosing operation. This is the first unit of this sort that I have seen, but it is a point that might be well

worth considering in the development of nose heating.

While the largest size shells are nosed hot, the smaller size shells such as 75 mm. and 90 mm. are nosed cold.

MEMBER: How was the slug heated originally?

J. L. YOUNG: There are many different types of furnaces for heating the slugs before forging, but the most universally discussed and adopted at this time is the rotary type furnace, and a number of manufacturers are now making furnaces of this type.

During a meeting in Cincinnati recently, Alan D. Dauch presented a paper on this subject following a general discussion by Professor Trinks, and I believe it would be best to ask Mr. Dauch to give a short resume of that story.

ALAN D. DAUCH: The paper on forging furnaces and heating rates presented at the Cincinnati meeting of the A.S.M.E., and referred to by Mr. Young, featured rotary hearth forging furnaces and their application in the heating of shell billets. In this paper three types of furnaces were discussed as being suited for use in the heating of shell billets, *i. e.* batch, pusher and rotary hearth. The rotary hearth furnace is to be preferred since it permits the loading of billets on end, spaced away from each other, maximum uniformity of heating, one man loading and unloading, control of heating time as well as temperature, and a reduction in heating time of almost 50 per cent.

The comparable fuel consumption as expressed in gallons of oil per ton of steel heated are: batch type, 45 to 60 gallons; rotary hearth type, 16 to 20; pusher type, 15 to 18, depending on the temperature, output and continuity of operation.

As a specific example of reduction in heating time we heat a 4½ in. square billet in a pusher furnace in 1 hr. and 32 minutes. This heating is for an upset operation in the manufacture of automobile ring gears. In the rotary hearth furnace we heat a 4½ in. square billet in 52 minutes. This heating is for an upset operation in the manufacture of an airplane engine forging. In both cases the furnace operating temperature is 2350 degrees F.

As an item of interest we might add that the maximum temperature permitted in the forging of British shells is 2200 degrees F., while 2300 degrees F. is the recommended maximum temperature in the forging of United States shells.

C. H. HUNT: I would like to know the capacity of the shell forging press.

J. L. YOUNG: The capacity of the press is 400 tons, but in that connection a very interesting thing has developed which is quite hard to believe, but nevertheless it seems true. The actual tonnage required for making a typical shell is between 40 and 50 tons, as nearly as the gauge can be read during the few seconds of forging. I have watched the gauge myself and others have seen it also, and I believe they will agree with this statement.

We believe that the theory of elimination of extrusion and the forming of the metal downward into the cavity with balanced pressure against the base is the reason for this unusual situation.

From a standpoint of production or shells per hour, we know that the press just referred to is making an average of about 60 shells per hour with one 14 ft. rotary furnace, and we feel certain that this can be doubled when the second furnace is installed.

C. H. HUNT: What eccentricity in the forged shell may be expected?

S. FINDLATER: A great many of the shell forgings have an eccentricity considerably less than 1/16 in. When some of the forgings exceeded that eccentricity, it appeared to be due to uneven billet temperature brought about by operating the furnace in excess of its capacity. I think that when sufficient furnace capacity is installed, the average degree of eccentricity will diminish.

J. A. SUCCOP: What type of steel is used in the punches of the shell forging press?

J. L. YOUNG: In our discussions with the various engineers and operators throughout the country, we find a great divergence of opinion as to the type of metal to be used in punches and in dies. For the "one shot" press, we have found that a close grained cast iron is satisfactory and they are obtaining an average of about 50 shells per punch tip and the punch tip can be redressed at least two times. We are also using a similar cast iron in the dies and apparently several thousand shells can be made before the dies must be redressed.

Experiments are going on with various types of iron and alloy steels for these two positions to see if greater life or lower cost per shell can be obtained.

C. H. HUNT: What is the cooling medium used on the punches?

J. L. YOUNG: Water.

J. L. COX: In your paper you state: "It was in 1838 that James Nasmyth, a Scottish engineer, conceived the idea and developed plans for the first direct acting steam hammer, as a necessity to forge the crankshaft for the steamer *Great Eastern* at Trafford Park, Manchester, England. This hammer was not built until some years later by French business men, and in 1848 Nasmyth received patents on his design."

In this account you have followed the usual story as told by Nasmyth, although your date of 1838 is earlier than I remember to have seen selsewhere. Let me take another opportunity to deny the truth of Nasmyth's account.

If the occasion of the invention was the necessity of such a tool for forging the *Great Eastern's* shafts, why did Nasmyth wait four years, and until after he had seen the Creusot hammer, before he built one and supplied the needed shafts? The facts are that in 1838 the Creusot Works had a working model of the hammer it built probably in 1840.

In 1842 my father acted as interpreter for Bourdon, the French inventor, when Nasmyth first saw the Creusot hammer. His account of the visit differed radically from that in Nasmyth's autobiography. He was needed as interpreter because Bourdon spoke English very badly, quite contrary to Nasmyth's statement that he spoke it fluently. My father had no

recollection of Nasmyth sketching on a board the laminated packing under the piston rod, which the latter said Bourdon and Schneider had missed in their hasty examination of his scheme book at his office in his absence, although earlier, in his account of that visit, Nasmyth said that they made careful notes and sketches of his drawing.

The Creusot hammer was extremely crude compared with Nasmyth's sketch and it is quite inconceivable that any engineer could have designed it who had ever seen Nasmyth's idea, which would do for a hammer of today.

Convincing proof of the invalidity of his claim to have invented the steam hammer is shown by the fact that on his return to England Nasmyth took steps to patent the hammer and offered the American agency for its sale to my father, a young man whom he had never seen before, of whom he knew nothing, who was only 20 years old, but just graduated from the Ecole Centrale in Paris; who had no business experience, no business connections with the United States, and had not been in America since he was seven years old.

Some years ago I published a full account of the whole matter in one of the technical papers, and gave to the Franklin Institute a tracing of the drawings of the Creusot hammer made by my father in 1842, shortly before Nasmyth's visit there, my father having been a guest of Francois Bourdon, chief engineer of the Creusot Works and the real inventor of the steam hammer.

Gilchrist Discussion . . .

(*Continued from page 25*)

in micro-inches, which is an indication of the necessity of a high polish. For instance, with a roll neck roughness reading of 16 micro-inches, we would have a wear reading of so much; that if we produced a roll neck with a micro-inch roughness of 32 to 33, we would obtain an increase in wear of approximately 200 per cent. These determinations were made with test specimen only, and not full size bearings, because the slow rates of wear in full size bearings are impractical for laboratory work. However as we know, results in the field have borne out the necessity for good roll necks and keeping them that way. But the point I wish to drive home is that roll necks cannot be polished too highly nor can too much care be given them.

As regards the breakage of slipper bearings, a matter which seems to be getting considerable attention here, I would like to draw to your attention the female part of the coupling. If the slipper does not fit properly to this portion of the coupling, by virtue of previous wear at its extremities with the use of metallic slippers, unsupport results and fatigue sets in from repeated flexure for each revolution of the mill.

Further, in those couplings where the pin does not extend through the female part of the coupling, all the load delivered to the pin by virtue of insufficient support of the spindle by the spindle carrier bearing, results in this load being carried by the slipper in the boss area opposite the pin hole. This being a weak section of the slipper, failure occurs by cracking at this point, under repeated stresses. This then indicated attention being given to the setting up of the spindle carrier bearing and making it do its full share of its intended work. The importance of this setting-up increases with the increase in angularity or cant of the spindle.

Another item for consideration is the applying of non-metallic slippers to the roll end of spindles. Considerable damage can be done during roll changes by virtue of the unwieldy methods of roll handling necessitated by circumstances. If protective means are not used, the edges and faces of the slippers will be beaten up when the fish tail enters. Also jamming a roll into place often delivers a shock to the coupling pins causing the slippers to crack in the boss area opposite the pin hole.

Mr. Atwater has submitted some worthy comments on how these above discussed conditions might be provided for, and I believe we have some too.

We have designed our slipper with alloyed bronze reinforcing edges in the longituinal axis of the slipper, simulating very closely the theory of "I" beams. By so designing we feel we have accomplished the following:

1—Increased moment of inertia in the boss area of slipper.

2—Provided protective edges for the slipper during roll changes.

3—Provided a mechanical bond to hold the slipper in an operative unit in cases where breakage might occur.

POWER CONSUMPTION of Hot Strip Mills

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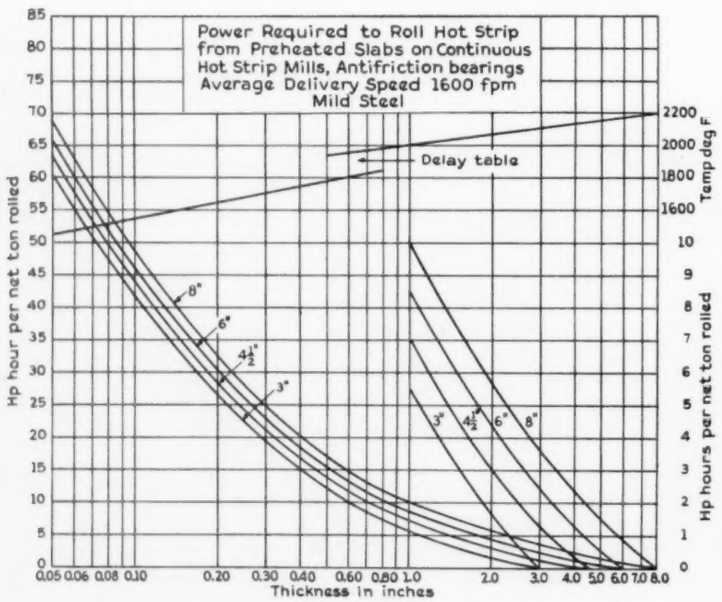
▲ IT is the purpose of this paper to present power consumption data collected on a large number of modern high speed continuous hot strip mills. Most of the mills considered are of the conventional arrangement; that is, four roughing stands with or without anti-friction bearings and six finishing stands with anti-friction bearings. The mill sizes range from 44 in. to 98 in. wide and the delivery speeds vary from 1200 ft. per min. up to 2000 ft. per min. No significant difference in power consumption, as expressed in kwh. per ton, was noted between mills equipped with roller bearings and those equipped with oil sleeve bearings; and no appreciable difference was noted between mills operating within the above limits of delivery speed.

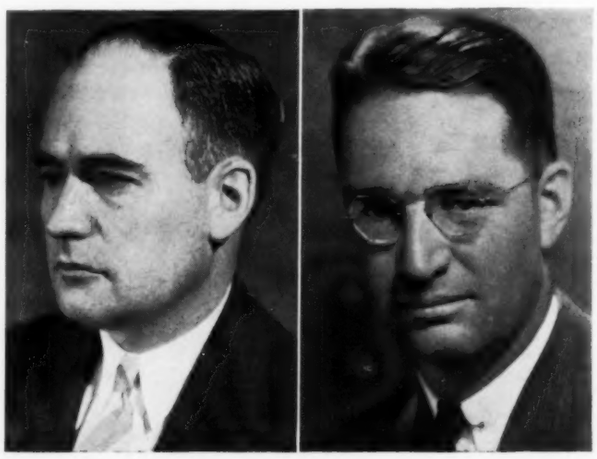
To better cover the entire subject, the paper is divided into two distinct parts. Up-to-date power curves expressed in terms of thickness versus hp.-hr. per net ton for mild steel and some alloy steels are included. Such curves are a storehouse of fundamental knowledge about power requirements, as they are independent of the common variables of width and speed. They are, however, sensitive to variation in rolling temperature and must be used with care in this respect.

Although several previous papers listed in the appendix thoroughly describe the methods used in obtaining the necessary data for plotting the curves, the procedure is repeated here for the sake of completeness. With accurate power curves available the horsepower requirements for any mill and for any rolling schedule may be easily calculated and the methods used for these determinations are included.

The energy consumption for a particular motor is measured by a kwh. meter totalled over a period of a month, and the average energy consumption per ton is

FIGURE 1


Power Required to Roll Hot Strip from Preheated Slabs on Continuous Hot Strip Mills, Antifriction bearings Average Delivery Speed 1600 fpm Mild Steel
Delay table
8"
6"
4½"
3"
Hp hour per net ton rolled
Temp deg F
Hp hours per net ton rolled
Thickness in inches



W. M. BALLENGER T. R. RHEA

obtained by dividing this monthly energy consumption by the total net tons rolled for that month.

Very little information has been published on the average energy input in kwh. per ton on main drives and auxiliaries. Although considerable data has been accumulated on a number of modern mills this paper will not attempt to compare the data of one particular mill with another, but will rather present a composite average, called a "national average"; and then each operating engineer may compare his own figures with it to see if his mill is above or below the national average. However, any comparison should be made on the basis of the same average rolled product. The various mills have been divided into two groups—one group being the medium width mills from 44 in. up to 60 in. wide and the other group those above this size.

PART I—POWER REQUIRED TO ROLL HOT STRIP

Energy consumption per net ton may be conveniently expressed in the form of curves, popularly called "power curves."

Figure 1 shows the power curves of thickness versus hp. hr. per net ton for mild steel on the basis of starting with 3 in., 4½ in., 6 in., and 8 in. thick slabs. These curves represent the accumulation of data over a number of years on a large number of modern hot strip mills. For the purposes of this paper, several additional tests were made on very modern mills as a check, and these final curves are applicable to any modern mill. Although the power curves presented are largely based on ten stand continuous mills with anti-friction bearings on all stands, they have been checked with satisfactory accuracy on mills with reversing roughing stands. It will be noted that the temperature gradient and effect of the delay table are shown.

Figure 2 shows the power curve of the more common alloys, high carbon, and high phosphorous steel. Figure 3 shows the power curve of stainless steel such as 18 per cent chromium and 8 per cent nickel.

Unfortunately, there is far less data available for the curves of Figures 2 and 3 than for those of Figure 1, and the authors would welcome further test data to check the accuracy of these alloy and stainless steel curves.

The procedure of taking data from which such curves are plotted is as follows:

(a) Such essential mechanical data as working roll diameters, gear ratios, screwdown settings, slab dimensions, slab weight, and finished width and thickness must be obtained from the roller.

(b) Temperature readings should be taken ahead of No. 1 scale breaker, after No. 4 roughing stand, ahead of No. 2 scale breaker, and after No. 10 stand for each slab during the test.

(c) Electrical data are comparatively easy to get on the modern mill which has recording wattmeters on the roughing stand motors, recording ammeters and tachometers on the finishing stand motors, and a recording voltmeter on the generator bus; all these instruments being equipped with high speed charts of at least 3 in. per min. Preferably recording tachometers should be checked with simultaneous readings on the pulpit indicating tachometers, calibration having been verified prior to the test.

FIGURE 2

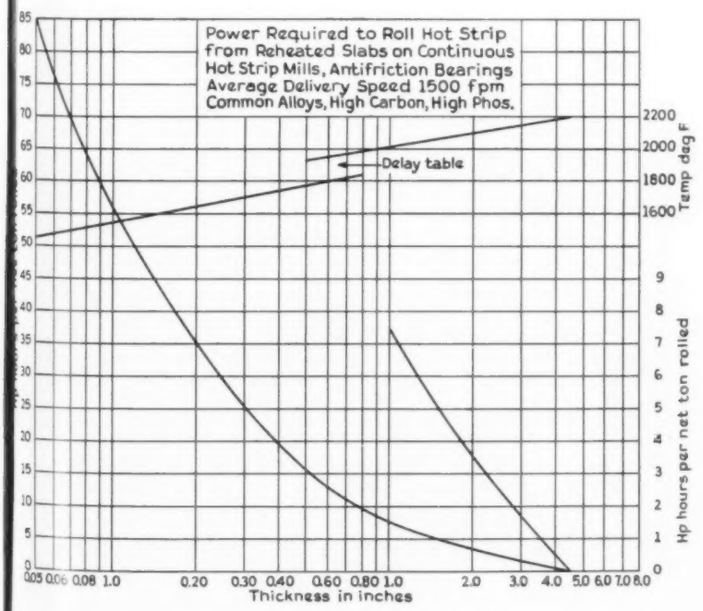
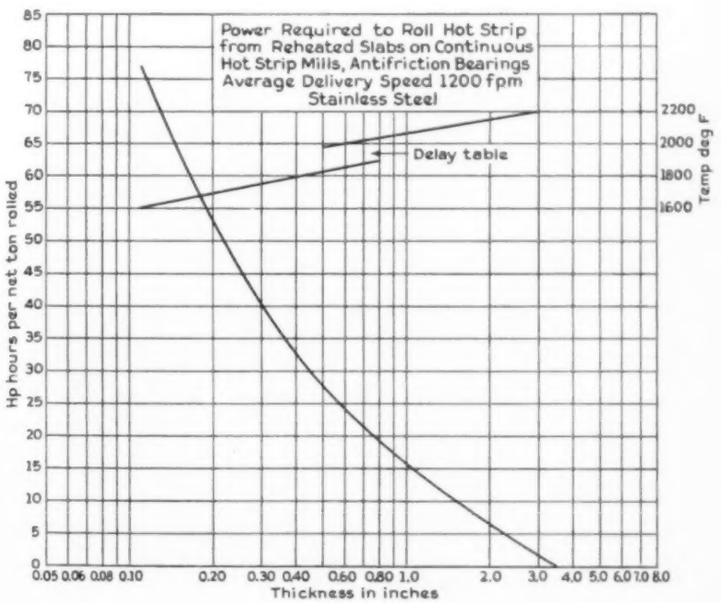

Power Required to Roll Hot Strip from Reheated Slabs on Continuous Hot Strip Mills, Antifriction Bearings Average Delivery Speed 1500 fpm Common Alloys, High Carbon, High Phos.
Delay table
Temp deg F
Hp hours per net ton rolled
Thickness in inches

FIGURE 3


Power Required to Roll Hot Strip from Reheated Slabs on Continuous Hot Strip Mills, Antifriction Bearings Average Delivery Speed 1200 fpm Stainless Steel
Delay table
Temp deg F
Hp hours per net ton rolled
Thickness in inches

(d) At least four sets of readings, preferably on consecutive slabs, should be taken and averaged.

(e) From the kw. input to each motor, subtract the motor losses* and convert to horsepower; in other words, determine the net horsepower per pass. The manufacturer of the motors will be glad to supply the information on motor losses. In the case of synchronous motors or wound rotor motors without flywheels on the roughing stands, this procedure is of course simple; but, in the case of wound rotor motors with flywheels the problem is somewhat laborious. H. A. Winne's "Determination of Motor Capacity for Main Roll Drives," June, 1932 issue of IRON AND STEEL ENGINEER describes two methods of procedure.

It is believed unnecessary to subtract an estimate of the idling mill friction loss and later to introduce another estimate of the same factor into the calculations when using the curves for the purpose of determining horsepower requirements. In any case this value is quite small and the authors have completely neglected its consideration. The authors have attempted only to get an accurate measure of the energy leaving the motor shaft during the rolling period.

(f) Although the roller has given the screwdown settings, or thickness after each pass, it is well to make a check of this important part of the data. Knowing the length of the original slab, the ft. per min. out of No. 1 stand, and the time the slab is in the mill (from chart or stop watch), it is an easy matter to check the thickness after No. 1 stand, and so on for the other roughing stands. Likewise, it is easy to calculate the thickness after each finishing stand. The thickness of finished strip is accurately known. Since the strip is in all six finishing stands simultaneously and the width is constant, the thickness must vary inversely with the delivery speed of the stands, and a very accurate calculation can therefore be made.

(g) The net tons per hour rate of rolling, as if the particular pass were continuously filled, is obtained by multiplying the area in square inches after the pass by ft. per min. and dividing by 10.

(h) Hp. hr. per net ton per pass are obtained by dividing the average net hp. per pass by the rate of rolling in net tons per hour.

(i) Hp. hr. per net ton are a summation of the hp. hr. per net ton per pass up to and including the particular pass or all passes.

(j) The results of these calculations are put in convenient form by plotting a curve of thickness versus hp. hr. per net ton, as shown in Figure 1.

We have reviewed the procedure followed in plotting the power curves. Now let us see how the curves may be used to determine horsepower requirements for a given rolling schedule. Assume a continuous hot strip mill with anti-friction bearings on all stands and an actual rolling schedule as given in Table I. Referring to this table the size of slab and finished section must be given; also columns A, B, and C must be given or readily calculated from other known data. Column D, the net tons per hour, may be easily figured on the basis of each pass being full 100 per cent of the time, by multiplying the values in columns A, B, and C, and dividing the product by 10.

At this point the calculator must choose a power curve. Since the material is mild steel and is to be rolled at the usual temperatures, the curve of the 6 in. slab in Figure 1 is the correct selection. For any other slab thickness it is easy to interpolate. The values in column E are taken from this curve, using thickness (column A) as abscissa points. Since the hp. hr. per net ton values taken from the curve represent total work done up to and including that particular pass, it is necessary to subtract the total of the preceding pass in order to get hp. hr. per net ton per pass (column F). For example, the total up to and including No. 3 roughing stand is 6.35 and the total up to and including No. 2 roughing stand is 3.45. The difference, 2.90 hp. hr. per net ton, is the work done in No. 3 roughing stand. Knowing the net tons per hour (column D) it is only necessary to multiply the values of columns D and F to obtain net rolling horsepower for each pass (column G).

The values in column G are the actual instantaneous motor rolling loads for the individual stands. The loads are usually assumed to be constant during the pass and represent the peak loads for the particular schedule considered.

A short cut method of determining the heating or root-mean-square value of these peak loads is to multiply the peak load of each stand by the square-root of the ratio of actual to theoretical rate of rolling for that stand. For example, take No. 4 roughing stand which has a peak load of 8110 hp., an actual rate of rolling of 200 net tons per hour, and a theoretical rate of rolling of 1220 net tons per hour. We find for this stand:

$$\text{Rms. hp.} = \sqrt{\frac{200}{1220}} \times 8110, \text{ or } 3300$$

Column H gives the minimum rms. horsepower for each stand as determined in the above manner. True, this neglects the effect of motor heating during the idling periods, but this has so little influence upon the motor rating that it may be disregarded for most calculations.

While it is not the primary purpose of this paper to discuss the selection of proper motor ratings, a few words on this subject may be in order. Of course, a large number of rolling schedules must be considered and the final motor selections would be based upon the heaviest schedules. Two factors are of importance in selecting motor ratings:

(a) Peak loads imposed.

(b) Heating, or root-mean-square loads.

In determining roughing stand motor ratings it is usually found that peak loads are the important consideration and heating is of little consequence. This is evident when comparing columns G and H. Whether or not wound rotor motors with flywheels are selected for the roughing stands will depend upon the length of pass in seconds and the interval between slabs. If any pass is longer than five or six seconds the flywheel combination becomes impracticable and a synchronous motor should be considered. Frequently a combination of wound rotor motors with flywheels on the first two roughing stands and synchronous motors on the third

*The shunt field losses of d-c. motors or field losses of synchronous motors are not subtracted since the recording meter reading does not include the field input.

and fourth roughing stands is more acceptable. On wide mills which broadside, wound rotor motors and flywheels are usually indicated. On such wide mills that broadside and also roll a large percentage of long narrow slabs for tin plate bands, a slip regulator setting that limits the motor input to 200 per cent is advisable. This permits the flywheel to level off the high but relatively short peaks when broadsiding, yet prevents the motor from slowing down excessively when rolling tin plate slabs where the peaks are moderate and the passes are long, possibly approaching ten seconds in No. 3 and 4 roughing stands.

In determining the finishing stand ratings, it is usually found that the predominating factor is heating, or root-mean-square load. As shown in Table I, the rms. hp. in column H is a much greater percentage of the peak load hp. in column G than in the case of the roughing stands.

A general rule is that the ratio of peak loads to motor ratings should not exceed the following:

Roughing stand a-c. motors without flywheels:

If designed for 250 per cent maximum torque, ratio = 175 per cent.

If designed for 300 per cent maximum torque, ratio = 200 per cent.

Finishing stand d-c. motors, 2:1 speed range, ratio = 150 per cent.

While standard mill type motors will carry greater peak loads, there are several variables that make such conservative ratios advisable.

By far the greatest variable affecting motor ratings is temperature of the steel, and ample allowances must be made in motor selections for this probability. For example, a 300 degree F. decrease in temperature means almost 100 per cent increase in rolling load, and 100 degrees F. decrease in temperature means about 25 per cent increase in rolling load.

The roller may not adhere strictly to the rolling schedule and may thereby increase the rolling loads on certain motors, and allowance must be made for this variable.

If the mill is to roll alloys and stainless steels, allowances as may be estimated from the relationship of curves of Figures 1, 2, and 3, must also be made.

The final selection of motor ratings requires a judicious use of the common sense factor to cover all of the expected variables and to make sure that the motor sizes will be adequate for all possible rolling conditions.

If the mill is equipped with plain sleeve bearings on the finishing stands, the curves are far too low, as the power requirements of such mills may be considerably more than for mills with roller or oil film bearings on the finishing stands. If the mill is equipped with plain

TABLE I

Calculation of Horsepower Requirements for a Given Rolling Schedule

Rolling 48¾ in. x .060 strip from 40 in. x 6 in. x 105 in.
Slabs weighing 7000 lb.—Mild Steel—200 net tons per hr.

Stand	A Thickness, in.	B Width, in.	C Delivery speed, ft. per min.	D Net tons per hr.	E Hp. hr. per ton, total	F Hp. hr. per ton, per pass	G Net rolling hp.	H Root-mean-square hp.
...	6.000	40	....	....	0	...	....	....
SB-1	5.750	40	270	6220	.20	.20	1244	223
R-1	4.100	105	172	7400	1.20	1.00	7400	1220
R-2	2.400	48¾	305	3570	3.45	2.25	8040	1900
R-3	1.400	48¾	410	2800	6.35	2.90	8125	2180
R-4	.608	48¾	410	1220	13.00	6.65	8110	3300
SB-2	.577	48¾	167	470	13.70	.70	329	215
F-5	.360	48¾	268	470	19.80	6.10	2870	1875
F-6	.215	48¾	450	470	28.80	9.00	4230	2760
F-7	.132	48¾	730	470	39.40	10.60	4980	3260
F-8	.093	48¾	1035	470	47.80	8.40	3950	2580
F-9	.073	48¾	1325	470	54.40	6.60	3100	2030
F-10	.060	48¾	1610	470	60.00	5.60	2640	1725

Column D, net tons per hour $= \frac{\text{width} \times \text{thickness} \times \text{ft. per min.}}{10}$

Column E, hp. hr. per ton total, is from 6 in. slab curve, Figure 1.
Column F, hp. hr. per ton per pass $= E - (E$ of preceding pass)
Column G, net rolling hp. $= D \times F$
Column H $= \sqrt{\frac{200}{D}} \times G$

sleeve bearings on the roughing stands and anti-friction bearings on the finishing stands, the curves may be used with sufficient accuracy, although it would be desirable to raise the final roughing stand horsepower calculations about 15 per cent. The same is true if a universal rougher with plain sleeve bearings is used. With anti-friction bearings on the universal rougher, the curves apply without any correction. In other words, there is no distinguishable difference between a mill with continuous roughing stands and a mill with a universal rougher as far as the power curves are concerned.

PART TWO—ENERGY CONSUMPTION OF HOT STRIP MILLS

A large amount of energy consumption data has been collected on modern hot strip mills. To facilitate analysis and comparison all such data must be put upon the same basis. This was done here by including all consumers of power from slab storage to piler—main drives, a-c. and d-c. auxiliaries, descaling pumps, and lights—but no service water or finishing department energy consumption. All readings taken on a-c. low voltage or d-c. feeders were corrected for equivalent main bus readings, 6600 volts for instance.

Metering practices vary somewhat among the steel plants. Some energy metered in the hot strip mill motor room may be consumed in other departments, and due allowance must be made for this in compiling the data.

Energy consumption data must necessarily be averaged over a definite period of time, say a month, and preferably several months should be considered to obtain a representative grand average. Corresponding total net tons rolled for the same period must also be obtained in order to determine the value of kwh. per ton, which is the real basis of comparison.

In analyzing the data it is important to consider the average product rolled, as obviously a mill regularly rolling down to an average of .085 in. thickness will have a higher kwh. per ton value than the same mill, or another similar mill, rolling down to only .129 in. thickness. Also, the rolling of alloy and high carbon steels will increase the energy consumption.

When comparing months of light production with months of medium or heavy production it is interesting to note that the kwh. per ton and average tons per hour remain fairly constant. This indicates that rolling schedules were sufficiently well planned so that a variation of almost 300 per cent in monthly production had little effect upon the kwh. per ton. Table II shows energy consumption of a modern wide hot strip mill over a period of seven months. The tonnage rolled varies from 33,000 to 88,500 net tons per month, yet the rate of rolling varies only between 141 and 166 net tons per hour. The energy consumption of main drives and auxiliaries is reasonably constant throughout the period.

Table III shows a comparison of months of light and

TABLE II

Energy Consumption of a Modern Wide Hot Strip Mill

Maximum speed 2000 ft. per min. No transfer tables.
Average product, .086 in. strip from 6 in. slabs.

	July, 1939	Aug.	Sept.	Oct.	Nov.	Jan., 1940	Feb.	Average
Net tons rolled	33,000	53,200	65,200	79,300	88,500	84,900	87,500	70,200
Net tons per hour	144	151	166	149	141	143	144	148
Kwh. per net ton (corrected for 6600 volts):								
Roughing stands	14.2	14.4	13.5	13.8	14.8	16.0	14.8	14.5
Main motor generator sets	38.4	40.6	38.4	38.3	40.0	39.6	41.3	39.5
Total, main drives	52.6	55.0	51.9	52.1	54.8	55.6	56.1	54.0
*Runout tables and coilers (d-c.)	3.0	3.0	2.7	2.7	2.9	3.0	2.9	2.9
Exciter motor generator set	2.5	2.5	2.1	2.1	2.2	2.3	2.3	2.3
250 volt d-c. auxiliaries	6.7	5.8	5.5	5.5	5.6	6.6	6.4	6.0
**A-c. auxiliaries and lights	17.4	15.1	13.5	12.6	12.0	12.2	13.2	13.7
Descaling pumps	7.5	8.2	7.2	7.7	8.0	8.4	8.3	8.0
Total main drives and auxiliaries	89.7	89.6	82.9	82.7	85.5	88.1	89.2	86.9

*Flying shear included.
**Contains some energy chargeable to hot strip finishing department.

heavy production on several different mills. Even though the tonnage rolled varies over a wide range the rate of rolling and the energy consumption of a particular mill are reasonably constant. Although it is not the purpose of this paper to compare mills, it is interesting to note that the differences in energy consumption of the main drives among the several mills may be attributed mainly to the corresponding differences of slab thickness and finished gauge. The total energy consumption of main drives and auxiliaries shows a wider variation between mills. This is due to differences in operating practice, the difficulty of metering auxiliaries accurately, and the problem of segregating energy consumed by other departments.

Table IV shows a comparison of energy consumption in months of light and heavy production of the major auxiliaries--250 volt d-c. auxiliaries, a-c. auxiliaries, lights and descaling pumps. As in the case of the main drives, monthly production has little effect upon the energy consumption of the auxiliaries for a particular mill. There is, however, considerable difference between mills especially in the energy consumption of the descaling pumps.

A composite average, called a "national average," of the data collected on these and several other mills is presented in Table V. The mills have been divided into two groups as indicated and corresponding data are included for both groups. Referring to the tabulation, comments are as follows:

1. Net tons rolled per month is an extremely variable factor. The value given is an arbitrary average that merely indicates how busy this hypothetical "average" mill is.

2. If your own mill differs much from the kwh. per net ton values given in the table, the reason is probably a difference in slab thickness and finished gauge. If your mill rolls to thinner gauges, the power consumption will be higher than the "average," and vice versa.

3. Again, the average net tons per hour are an arbitrary value, representative of the mills considered.

4. The kwh. per ton consumed by the roughing stands of the medium width mills are low, because of thinner

TABLE III

Energy Consumption of Several Medium and Wide Hot Strip Mills

(Comparing months of light and heavy production)

Mills	Net tons rolled		Kwh. per net ton			
Listed in order of size (44 to 98 in. wide) and giving average product	Per month	Per hour	Roughing stands	Main motor generator sets	Total, main drives	Total, main drives and auxiliary
A—4½ to .083 in.						
Heavy production	58,000	110	9.8	42.0	51.8	83.7
B—4½ to .08 in.						
Light production	31,823	94	11.2	43.7	54.9	81.6
C—5 to .110 in.						
Light production	13,521	53	14.0	40.5	54.5	80.0
Heavy production	44,878	68	13.6	39.7	53.3	75.0
D—4 to .095 in.						
Light production	31,245	101	10.0	33.4	43.4	75.0
Heavy production	56,245	104	11.5	36.1	47.6	80.0
E—6 to .086 in.						
Light production	33,000	144	14.2	38.4	52.6	90.0
Heavy production	88,500	141	14.8	40.0	54.8	85.5
F—5½ to .080 in.						
Heavy production	85,340	137	14.1	42.9	57.0	95.4
G—4¼ to .090 in.						
Heavy production	92,400	130	13.0	37.8	50.8	81.0
H—4½ to .085 in.						
Light production	26,300	125	12.4	38.6	51.0	74.0
Medium production	69,200	114	10.5	38.7	49.2	71.0

slabs and also because synchronous motors or induction motors without flywheels are used, thus eliminating the appreciable slip regulator and flywheel windage losses.

5. When the finished thickness is approximately the same, the main motor-generator set power consumption is practically identical on all mills. Since the medium width mills roll to slightly thinner gauge, the kwh. per ton are correspondingly higher than on the wider mills.

6. In considering the total kwh. per ton of main drives, the question may immediately arise that such and such mill has a lower energy consumption than this "average." Indeed it may have. Figures on one excellent and well operated mill over a three months period indicated only 46 kwh. per ton for the main drives, as compared with the national average of 55 kwh. per ton, but the average rolling was 4½ in. slabs down to .129 in. strip. There lies the answer.

7. Kwh. per ton for runout tables and coilers depend to some small extent upon whether there are transfer tables, but to a much greater extent upon whether the drives are a-c. variable frequency or d-c. Ward-Leonard. The power consumption of a-c. drives is at least 5 kwh. per ton, whereas the power consumption of d-c. drives does not exceed 3 kwh. per ton.

8. The kwh. per ton for the flying shear are very low because of the nature of the load.

9. Exciter motor generator set kwh. per ton are possibly a little higher on mills having synchronous motors on the roughing stands, but this can be counteracted to some extent by automatically reducing motor excitation during idling periods. The amount is small anyway.

10. The power consumption of the 250 volt d-c. auxiliaries varies somewhat with different mills and this may be largely due to the difficulty of accurately segregating power consumed by other departments.

11. The same comments apply to the kwh. per ton of the a-c. auxiliaries and lights.

12. The power consumption of motor room fans was found to be approximately the same for all mills.

13. The descaling pumps appear to have a rather wide variation in energy consumption, probably due to the method of operation.

TABLE IV

Energy Consumption of Major Auxiliaries of Several Medium and Wide Hot Strip Mills

(Comparing months of light and heavy production)

Mills Listed in order of size (44 to 98 in. wide) and giving average product	Net tons rolled		Kwh. per net ton		
	Per month	Per hour	230 volt d-c. auxiliaries	A-c. auxiliaries and lights	Descaling pumps
A—4½ to .083 in.					
Heavy production	58,000	110	7.3	6.3	12.7
B—4½ to .08 in.					
Light production	31,823	94	6.0	7.2	6.2
C—5 to .110 in.					
Light production	13,521	53	4.4	7.0	8.6
Heavy production	44,878	68	2.5	5.0	6.0
D—4 to .095 in.					
Light production	31,245	101	5.5	8.6	8.7
Heavy production	56,245	104	6.7	7.9	9.4
E—6 to .086 in.					
Light production	33,000	144	6.7	17.4*	7.5
Heavy production	88,500	141	5.6	12.0*	8.0
F—5½ to .080 in.					
Heavy production	85,340	137	7.7	4.6	16.2
G—4¼ to .090 in.					
Heavy production	92,400	130	4.0	4.00	13.8
H—4½ to .085 in.					
Light production	26,300	125	5.2	4.7	6.8
Medium production	69,200	114	3.0	3.6	9.2

*Contains some energy chargeable to hot strip finishing department.

14. The total energy consumption of main drives and auxiliaries for the "average" mill is either 82 or 86 kwh. per ton, depending upon whether or not the mill has roughing stand drives without flywheels and d-c. runout tables and coilers.

SUGGESTIONS FOR ENERGY SAVINGS

A study of energy consumption data on a large number of individual mills suggests several ways by which energy may be saved. On the basis of a power cost of one-half cent per kwh., a reduction of 1 kwh. per net ton means a saving of $3,000 annually on a hot strip mill rolling 600,000 net tons per year; likewise, a saving of $4,500 annually on a wide hot strip mill rolling 900,000 net tons per year. Thus, each kwh. saved is money in the bank. Some suggested savings on an assumed 600,000 ton per year mill are:

(a) On any new mill or contemplated change of an existing mill serious consideration should be given to synchronous motors on the roughing stands and d-c. runout tables and coilers. Together they may effect a saving of as much as 5 kwh. per ton, or $15,000 per year.

(b) On mills having induction motors with flywheels on the roughing stands the slip regulators are often set at 100 per cent kw. input. By increasing the setting to 200 per cent a saving of approximately one kwh. per ton, or about $3,000 per year will be effected for all roughers. This simply means that less energy is dissipated in the slip regulator, particularly on stands No. 3 and No. 4 and when rolling long slabs. Motors will stand the higher loads without danger of overheating because of the low time factor. The higher momentary peaks will have no effect upon the 15 minute demand.

(c) When the rolling schedule permits, one of the main motor-generator sets may be shut down. A wide mill that rolls tin plate slabs 50 per cent of the time can comfortably carry the load with one of the three main motor-generator sets shut down, at a saving of approximately one kwh. per ton, or $3,000 per year.

(d) The blowers on a recirculating ventilating system may be shut down perhaps during the three or four cold months of the year—another one-half kwh. per ton (averaged over the entire year) and a saving of $1,500 per year.

(e) Some of the modern hot strip mills have power factor regulators to govern the reactive kva. input to the main motor-generator sets. Although the regulator is installed for other reasons, it saves sufficient excitation and line losses to account for another one-half kwh. per ton or $1,500.

(f) The descaling pumps are large consumers of power. Table IV shows a power consumption of from 6.2 kwh. per ton up to 16.2 kwh. per ton on the different mills. The average on these and other mills is somewhere between 10 and 12 kwh. per ton but is conservatively listed as 10 kwh. per ton in Table V. Careful control of the operation of descaling pumps would pay dividends. Some operating engineers state that they can get along by running only two of the three pumps and thereby saving power. One operating engineer states that he has cut the energy consumption of his descaling pumps from 13 or 14 kwh. per ton down to 9 kwh. per ton by the use of a hydrostatic accumulator.

(g) Some auxiliaries such as delay tables, where starting and stopping are frequent and resistor losses are high, might justify Ward-Leonard drives at some saving in power.

It might appear that the authors are about to suggest saving all of the power and running the mill on perpetual motion. Even though small, the savings are well worth while and none of them entail any sacrifice of production.

Where a hot strip mill operates on purchased power the greatest single factor in power costs may be the demand charge. Any scheme for limiting the demand may affect production and must be considered from that point of view.

TABLE V

Energy Consumption of an Average Hot Strip Mill

	Medium width mills (44–60 in. wide)	Wide mills (above 60 in. wide)
1. Average net tons rolled per month.	60,000	75,000
2. Average size of slab, in.	33 x 4½	48 x 5½
Average size of finished product, in.	32 x .08	47 x .085
3. Average net tons per hour	100	140
Average kwh. per net ton: (Corrected for 6600 volts)		
4. Roughing stands	10*	14.0**
5. Main motor generator sets	42	41.0
6. Total, main drives	52	55.0
7. Runout tables and coilers	3 (d-c.)	4.0 (a-c.)
8. Flying shear	0.6	0.6
9. Exciter motor generator set	2.0	2.0
10. 250 volt d-c. auxiliaries	6.0	6.0
11. A-c. auxiliaries and lights	7.0	7.0
12. Motor room fans	2.0	2.0
13. Descaling pumps	10.0	10.0
14. Total, main drives and auxiliaries	82.6	86.6

*Synchronous motors.
**Induction motors with flywheels.

TABLE VI

Demand of Hot Strip Mills

	Medium width mills 44–60 in. wide, kw.	Wide mills Above 60 in. wide, kw.
Maximum instantaneous demand:		
Roughing drives	5,000 to 6,000	8,000 to 11,000
Main motor generator sets	15,000 to 18,000	24,000 to 33,000
Total main drives	18,000 to 22,000	27,000 to 36,000
Total main drives and auxiliaries	23,000 to 28,000	32,000 to 40,000
Maximum 15 minute demand:		
Total main drives	13,000 to 15,000	17,000 to 23,000
Total main drives and auxiliaries	15,000 to 18,000	20,000 to 26,000

Unfortunately, metering practices are such that it is a bit difficult to get accurate demand figures. Other loads are usually included and these are hard to segregate from a demand standpoint. Individual hot mill units may be equipped with demand meters but the diversity factor of the load prohibits straight addition of the demands.

Some figures have been collected, however, and are shown in Table VI.

It is well to repeat that instantaneous peaks on roughing stands without flywheels have no effect on the 15 minute demand and likewise have no effect upon the tonnage output.

SUMMARY

The power curves of Figures 1, 2, and 3 may be used to determine the kwh. per ton for any specific or average rolling schedule. For example, our "average" wide strip mill in Table V rolls 5½ in. slabs down to .085 in. strip at an average rate of 140 net tons per hour. From the proper curve of Figure 1, we find that the total work done is 50 hp. hr. per net ton. The overall efficiency of the main drives is about 85 per cent; therefore we may easily convert:

$$\frac{50 \times .746}{.85} = 43.8 \text{ kwh. per ton at 6600 volts.}$$

This is the power consumed while actually rolling steel and to it we must add the idling losses of the main drives, as the mill is full only about one-third of the time. The ratio of actual rolling rate to theoretical rolling rate is called the time factor. Experience proves that it averages no better than 33 to 35 per cent on any hot strip mill, and the wider the mill the lower the percentage. Tests on several mills indicate that the power required by the main drives during idling periods is from 1200 kw. to 1600 kw. on the medium width mills and from 2300 kw. to 2700 kw. on the wider mills. On basis of a time factor of 35 per cent (idling factor of 65 per cent) and 2500 kw. idling power, we find:

$.65 \times 2500 \times 1$ hr. $= 1625$ kwh., and

$$\frac{1625}{140} = 11.6 \text{ kwh. per ton at 6600 volts.}$$

Adding 43.8 and 11.6 we get 55.4 kwh. per net ton as a check against the 55 kwh. per ton value given in Table V.

For any specific rolling schedule, such as the one given in Table I, the kwh. per ton may be determined in the same manner. The time factor would of course be higher than the average value used in the example and may be easily figured for that particular schedule. To obtain the total kwh. per ton of main drives and auxiliaries, add about 32 kwh. to the main drive figure, although the average of 32 kwh. for auxiliaries may be slightly high when considering only one schedule.

The importance of this time factor cannot be overstressed. When we see that 20 per cent of the main drive power consumption of our "average" mill goes into idling losses during average rolling, we can appreciate how the energy consumption may go up during periods of light rolling if the mill is not scheduled to maintain correspondingly high tons per hour.

DISCUSSION

PRESENTED BY

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A. R. DIBBEN, *Assistant Electrical Superintendent,* Youngstown Sheet and Tube Company, East Chicago, Indiana.

W. M. BALLENGER, Engineering Department, General Electric Company, Chicago, Illinois.

G. E. STOLTZ, *Manager,* Metal Working Section, Industry Engineering Department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pennsylvania.

A. F. KENYON: The net energy consumption curves shown in Figure 1 have been checked with similar curves accumulated from tests which we have made, and agree quite closely, although it should be emphasized that variations in steel temperature, low rolling speeds, and other variables may affect the power requirements by as much as 15–20 per cent. It is of interest to note that the unit energy required to reduce to any particular finished thickness is not greatly affected by the thickness of the slab from which the strip is rolled, even though the elongation from a thick slab is much greater than from a thin slab. This would suggest the economy of rolling from fairly heavy slabs as the slightly increased work in the strip mill may be more than offset by the saving in the slabbing mill.

We concur with the authors' observation that where roughing stands are equipped with flywheels and driven by wound rotor induction motors, the slip regulator setting may advantageously be made 200 per cent or more of the motor rating. However it must be kept in mind that an induction motor assumes load only by slowing down to the speed where the secondary voltage is sufficient to circulate the required current through the secondary winding and any external secondary resistance. Even with the slip regulator electrodes at their minimum separation, a very appreciable resistance—several times the motor winding resistance—is introduced in the motor secondary circuit, and it is essential that the regulator capacity and adjustment be such that this permanent resistance is reduced to a minimum, in order to secure the maximum advantage from the high regulator setting.

The authors have pointed out the economy of using synchronous motors for the drive of some or all of the roughing stands, and it is of interest to note that synchronous motors have been applied to a number of medium width mills, and recently in the rearrangement and widening to 80 in. of one of the older mills 4000 hp. and 5000 hp. synchronous motors were installed for the drives of the No. 2, 3 and 4 stands.

From Table IV of the paper, the energy consumption of the descaling pumps is reported as varying on different mills from a minimum of about 6.0 to a maximum of about 16.2 kwh. per ton of strip rolled. From other mills we have observed data showing a range of from less than 9 to more than 18 kwh. per ton. Thus in

many mills the pumping of high pressure water for this surface treatment of the steel uses nearly as much energy as the entire group of roughing stands. If some mills are able to descale satisfactorily with energy consumption of 7–9 kwh. per ton, it would appear that other mills now using 12–15 or more kwh. per ton could make worthwhile savings in power cost and probably in other ways also by improving the operation and control of the descaling equipment.

F. D. EGAN: The power curves as obtained by the authors should prove of great value for calculation of motor sizes and power requirements for future installations, or for changes in existing equipment to accommodate heavier rolling schedules. I suggest that those of us that have equipment available follow the authors' suggestion and obtain test data, in accordance with the procedure as outlined in this paper, especially while rolling stainless steel, and high carbon steels. Such material will be of value to the industry and is worthy of our consideration.

In order to add to the discussion of energy consumption of hot strip mills, I have had prepared a tabulation of energy per ton required at Bethlehem's 76 in. hot strip mill this year to date. This data can be compared with that of the authors, and has been determined using net finished tons.

With reference to the authors' suggestions for savings in energy consumption, I feel that they are valuable and investigation should be made to determine which ones are practical for our individual mills.

So far in operation at the Lackawanna plant, we have not found it practical to operate with only one of the main motor generator sets, nor have we found it possible even in colder weather to shut down any of the blowers on the recirculating ventilation system.

With respect to the operation of the descaling pumps, we note that the author says that some operators get satisfactory operation running two of their three pumps. However, we have only two descaling pumps, and run only one at a time. This operation gives satisfactory results, and probably accounts for the relatively low value of kwh. per ton that we have for this drive.

It has been our practice in the past to operate with only one of the auxiliary motor generator sets, which would tend to cut down the value of auxiliary kwh. per ton. Due to the addition of finishing equipment throughout the mill, it has been found necessary to operate both machines, but during off days when the mill is not rolling, only one machine is left in operation.

A. R. DIBBEN: Mr. Ballenger and Mr. Kenyon both stressed this point on synchronous motors versus induction motors, and it wasn't quite clear to me. I wonder if Mr. Ballenger would explain that a little more fully, the advantages and disadvantages of one against the other.

W. M. BALLENGER: In commenting upon Mr. Dibben's question, we wish to make it clear that no distinction is drawn between synchronous motors and induction motors without flywheels (operating with the slip rings short-circuited), as far as power consumption is concerned. In the case of induction motors with flywheels there are appreciable secondary slip regulator losses and flywheel windage losses that noticeably increase the power consumption of the roughing stands.

G. E. STOLTZ: In general it is practice to either install wound rotor induction motors with flywheels or synchronous motors on the roughing stands of a hot mill.

There are two reasons why induction motors with flywheels which is the most expensive application are installed in preference to synchronous motors. The duration of passes on the roughing stands are very short and the percentage in time steel is in the roll is small. This makes an ideal application for flywheels. The peak loads on these stands are high, and unless a flywheel is used there is some possibility of tripping the overloads and possibly leaving the metal in the rolls. If a wound rotor motor with flywheel is used the flywheel of course will carry the piece through even though the motor would become overloaded and the circuit breaker tripped. This is not likely to happen as the distribution of load between the motor and flywheel is usually such that the motor does not carry a heavy load. The other reason is that a power system may be small making it inadvisable to throw the peak loads directly onto the generating or substation.

(*Please turn to page 72*)

KILOWATT-HOURS PER TON

Month	Tons	Rough stands	Main motor generator sets	Total main drives	A-c. auxiliaries	D-c. auxiliaries	Total auxiliaries	Descaling pumps	Total energy
January	82,020	10.8	37.3	48.1	15.8	5.4	21.2	5.5	74.8
February	57,898	11.0	38.0	49.0	17.1	5.6	22.6	5.2	76.8
March	43,660	10.9	38.1	49.0	20.4	6.2	26.6	5.3	80.9
April	37,301	10.7	34.4	45.1	19.8	5.9	25.7	5.1	75.9
May	59,276	10.3	33.4	43.7	14.8	5.1	19.9	5.0	68.6
June	63,497	10.7	36.2	46.9	15.5	5.1	20.6	5.3	72.8
July	73,337	10.5	35.0	45.5	15.0	5.1	20.1	5.3	70.9
August	85,621	10.5	33.6	44.1	13.9	5.4	19.3	5.3	68.7
8 month average	62,812	10.7	35.6	46.3	16.0	5.4	21.4	5.3	73.0

Energy to main motor generator sets includes energy taken by variable frequency runout tables.
Both a-c. and d-c. auxiliaries include some energy to finishing departments.

Effects of Storage and Oxidation of Coal Upon Coking Properties

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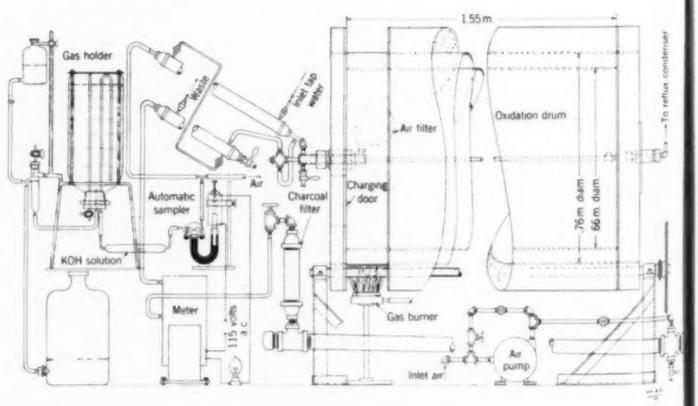
▲ IT is not far wrong to say that coal starts to "burn" as soon as it is broken from its bed in the mine and is exposed to air. That is, even though a lump of coal is cold to the touch, it is uniting with the oxygen of the air at a measurable rate and will continue to do so for a great many years. The gaseous products given off by this low-temperature "combustion" are exactly the same as when the coal is burned at high temperature in the furnace, namely, carbon dioxide, carbon monoxide, and water. The greatest difference between this high- and low-temperature oxidation lies in the lower rate at low temperatures and in the fact that at low temperatures about half of the oxygen consumed remains upon the coal, often causing the coal to gain in weight instead of wasting away.

It is a well-known fact that the coking power of all coals can be destroyed by storage in air for a sufficiently long time. Coke makers should understand the subject of oxidation in storage because such an understanding can easily lead to substantial economies in plant operation, owing to improvement in storage methods and in ways of controlling the effects of storage, thus allowing more coal to be stored.

Figure 1 shows the apparatus that was designed and built by the Bureau of Mines, United States Department of the Interior, for accelerated weathering of 400 lb. samples of 0 to ¼-inch coal.[1] The double-jacketed drum is half-filled with coal and rotated slowly while air is passed over the coal. Water boiling in the outside jacket maintains the coal at 211 degrees F. The amount of oxygen consumed by the coal is measured by gas analyses of the effluent air. Under these conditions coal oxidizes and loses its coking properties roughly 100 times as fast as in storage in air at ordinary outside temperatures. This factor of 100 is subject to considerable revision but is better than a mere guess.[2] The sources of nine of the coals that have been oxidized and carbonized to date are given in Table I. The coals are listed in the order of decreasing volatile matter content. High Splint has about 40 per cent volatile matter and Pocahontas about 18 per cent (ash- and moisture-free), with the rest distributed fairly evenly between these two.

It is very important that the reader should realize that the length of time a given coal can be exposed to air without serious impairment of its coking power depends on two separate and distinct properties of the coal: (1) the rate of consumption of oxygen under standard conditions; (2) sensitivity of the coking power to oxygen—that is, the quantity of oxygen required to impair the coking power. Some coals, notably the high-volatile coals, show high rates of oxygen consumption under standard conditions but can consume a relatively

Figure 1—Apparatus designed and built by the Bureau of Mines for accelerated weathering of 400 lb. samples of 0–¼ in. coal.



Presented before Annual Joint Meeting of Eastern States and Chicago District Blast Furnace and Coke Oven Association, Chicago, Illinois, October 11, 1940. Published by permission of the Director, Bureau of Mines, United States Department of the Interior.

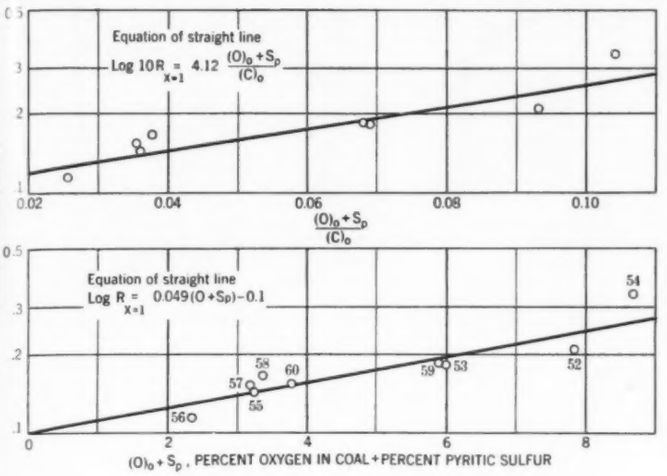


Figure 2—Graphs showing relation between rates of oxidation and chemical constituents of coals.

large amount of oxygen without much harm being done. Conversely, some coals are relatively sensitive to small amounts of oxygen but show a compensating low characteristic rate of oxidation and so may store just as well or perhaps better. However, the two properties, rate of oxidation and sensitivity, often do not compensate each other. Other properties, such as friability, size, and size degradation on storage, of course bear directly on storing properties but will not be discussed in this paper.

In Figure 2 (lower graph) the characteristic rates of oxidation of the nine coals are plotted against the percentage of oxygen plus the percentage of pyritic sulphur in the fresh coal. The pyritic sulphur content of these coking coals is low compared to the oxygen content, so we would get about the same thing if merely the percentage of oxygen in fresh coal were plotted. Furthermore, since the percentage of oxygen in fresh coal, in general, increases with increasing content of volatile matter, we should get about the same type of curve if the characteristic rate of oxidation were plotted against the percentage of volatile matter content of fresh coal.

This figure shows that the characteristic rate of oxidation increases from about 0.115 lb. of oxygen per 100 lb. of coal per day for Pocahontas No. 3 coal (No. 56, a coal of low oxygen and low volatile-matter content) to about 0.34 for High Splint coal (No. 54, a coal of high oxygen and high volatile-matter content). Thus, under standard conditions the most oxidizable coal tested consumes oxygen about three times as rapidly as the least oxidizable coal tested.

In the upper graph of Figure 2 the points fall a little more closely along a straight line. Here the characteristic rate of oxidation for the nine coals is plotted against the sum of the percentage of oxygen plus pyritic sulphur in fresh coal, divided by the percentage of carbon.

Table II attempts to give a sense of proportion on the relative importance of the various factors that affect the observed rate of oxidation of a coal.

Given two coals, *A* and *B*, *A* being the most oxidizable coal tested (High Splint) and *B* being the least oxidizable coal tested (Pocahontas No. 3), the characteristic rate of oxidation of coal *A* is three times that of coal *B*. That is, under identical conditions coal A consumes oxygen three times faster than coal *B*.

The table lists five separate sets of conditions under each of which the two coals would consume oxygen at the same rate. Some of the values given are subject to considerable revision as experimental work proceeds, but they are given here to illustrate the relative importance of the different conditions of oxidation.

TABLE I

Source of Coals Tested

Coal No.	Bed	Mine	Place	County	State
54	High Splint	Closplint	Closplint	Harlan	Kentucky
52	Pittsburgh	Bruceton	Bruceton	Allegheny	Pennsylvania
53	Pond Creek	Majestic	Majestic	Pike	Kentucky
59	Upper Freeport	.....	.....	Monongalia	West Virginia
60	Lower Freeport	.....	.....	Indiana	Pennsylvania
58	Lower Banner	Keen Mountain	Hangar	Buchanan	Virginia
55	Sewell	Wyoming	Wyoming	Wyoming	West Virginia
56	Pocahontas No. 3	Buckeye No. 3	Stephanson	Wyoming	West Virginia
57	Pocahontas No. 4	No. 4	Affinity	Raleigh	West Virginia

EFFECT OF TEMPERATURE*

If samples of the above two coals (*A* and *B*) are allowed to oxidize under exactly the same conditions, except that coal *B* is at 84 degrees F. and coal *A* is at 60 degrees F., both samples will consume oxygen at the same rate. In other words, a rise in temperature of as little as 24 degrees F. suffices to overcome completely the large difference in characteristic rate of oxidation. The average effective temperatures of any two large piles of coal could easily differ by 24 degrees F., and furthermore it would be very difficult to measure the average effective temperature of a large pile of coal within 24 degrees F.; yet, according to these data, that temperature difference is sufficient to triple the rate of consumption of oxygen.

EFFECT OF SIZE

Size of coal is also an important factor. If coal *A* and coal *B* are oxidized under exactly the same conditions, except that the sample of coal *B* is 18-mesh and the sample of coal *A* is 1-inch coal, then, according to the author's analysis of Winmill's data, the observed rate of consumption of oxygen would be the same for the two coals. Likewise, if coal *B* were 48-mesh and coal *A* ¼ in., both would show the same rate of oxidation.

EFFECT OF OXYGEN CONCENTRATION

Little information has been published on the percentage of oxygen in the air inside a large pile of coal. The successful storage obtained by close packing[5] and even by covering piles with a more or less impermeable cover[6] indicates that it is practicable to exclude oxygen sufficiently to improve storage. The author strongly recommends that operators obtain and publish data on the percentage of oxygen and carbon dioxide in the air in large piles of coal. The effects of such variables as close packing, wind, weather, covering, and temperature should also be observed. Better storage methods should be evolved by close study of this variable.

In the laboratories of the Bureau of Mines the effect of the percentage of oxygen in the air upon the rate of consumption of oxygen has been measured,[1] and the results are given in Table II. If coal *B* is oxidized in normal air (20.9 per cent oxygen) and coal *A* is under exactly the same conditions, except that it is in an atmosphere containing only 3.5 per cent oxygen, the two coals would consume oxygen at the same rate. In other words, decreasing the percentage of oxygen from 20.9 to 3.5 cuts the rate of oxidation of a coal to one-third.

EFFECT OF TIME SINCE OXIDATION STARTED

It is a well-known fact that the new surfaces of a freshly broken piece of coal consume oxygen at a relatively high rate. This initial high rate drops rapidly with time at first and then finally approaches a more nearly constant rate. The rate falls more rapidly with time in the case of fine coal. As shown in the table, if the samples of coals *A* and *B* are both fine coal the rate of oxidation of the two samples would be the same if the rate for *B* were measured 12 hours after crushing and the rate for *A* 2.9 days after crushing.

Figure 3—Effect of oxidation of Sewell bed coal: A—fresh coal; B—oxidized for 5.6 days; C—oxidized for 18.8 days.

It is interesting to note that the initial rapid decrease in rate of oxidation with time is probably responsible for the observation by Stoek[7] and others that most fires occur during the first three months of storage.

EFFECT OF AMOUNT OF OXYGEN THAT HAS BEEN CONSUMED

This factor depends on the same effect as time since oxidation started. If both samples are fine coal, the rates of oxidation are the same when coal *A* has consumed about twice as much oxygen as coal *B*.

As each of the factors given above serves to triple the rate of oxidation of a coal it is clear that the changes in conditions indicated in Table II could make coal *B* consume oxygen 27 times faster than coal *A*. The conclusion is plain; if the relative storing properties of different coals are to be measured, either the effect of any changes in the conditions of oxidation must be understood thoroughly and proper allowance be made, or these conditions must be maintained constant. Furthermore, these considerations give hope that even coals showing the poorest storing qualities can be stored successfully if a little attention is paid to making the storage conditions right.

Table III shows the changes in proximate and ultimate analyses caused by oxidation of the coal. When an average sample of 0 to ¼ in. coal has been in air at 211 degrees F. for 4.5 days the coal will have consumed one per cent of its weight of oxygen. It should be mentioned that this consumption of oxygen is sufficient to impair seriously the coking power of three of the most sensitive coals tested. It would be very convenient if we could measure the extent of oxidation of a given sample of coal by the ultimate and proximate analyses of the sample; however, each one of the changes given in Table III is uncomfortably close to the experimental error of the present laboratory methods. The largest change given is the 0.905 per cent increase in real

*The data on effect of temperature were obtained by analysis of the published work of Winmill and Graham, in England, working on 200-mesh coal.[3]

specific gravity of the coal. However, the measurements of real specific gravity were made on only two coals, and this increase may not prove to be general for all coals.

TABLE III

Changes in Proximate and Ultimate Analysis with Oxidation of Coal

Changes in proximate and ultimate analyses based upon the average for nine coals oxidized at 211 degrees F.
(Moisture- and ash-free basis)

Oxygen consumed, per cent by weight of coal	1
Days in air at 211 degrees F. (0–¼ in. coal)	4.5
Decrease in heating value, per cent	.69
Decrease in carbon content, per cent of coal	.40
Increase in oxygen content, per cent of coal	.49
Decrease in volatile-matter content, per cent of coal	.6
Increase in real specific gravity of coal,* per cent	.905

With the prevalent laboratory methods the author believes that, among the values given in this table, the best single measure of extent of oxidation is the 0.69 per cent decrease in heating value. The reader should understand that the changes given in this table are the apparent changes; that is, part of the loss in heating value per pound of coal, for example, is due to the increased weight of coal because part of the oxygen consumed remains upon the coal.

All these coals were carbonized in cylindrical steel retorts containing 180 lb. of 0 to ¼ in. coal. These retorts were heated in a furnace maintained at 800 degrees C.[8] By-product recovery and testing were done by standard methods. Pictures of typical pieces of coke made from each oxidized coal are shown in the series of technical papers of the Bureau of Mines covering the carbonizing properties of these coals.[9]

Figure 3 shows the effects of oxidation of Sewell-bed coal (No. 55). Piece *A* was made from fresh coal. Piece *B* was made from coal that had been oxidized for 5.6 days in air at 211 degrees F. and had consumed 0.86 lb. of oxygen per 100 lb. of moisture- and mineral-matter-free coal. Piece *C* was made from coal that had been oxidized for 18.8 days and had consumed 2.3 lb. of oxygen per 100 lb. of coal.

Usually, the first visual evidence of oxidation of the coal is finer cell structure in the coke, followed later by weak and pebbly coke formed inside of the retort, where the rate of heating is lowest. Further oxidation of the coal results in loose char being formed in the entire middle part of the retort. At this advanced stage of oxidation the coke that is formed near the outside of the retort is weak and pebbly and shows about a 5 per cent increase in apparent specific gravity.

In Figure 4 the strength of coke from each coal tested is plotted against the amount of oxygen that has been consumed by the coal. Coke strength† is the weighted average of the 1½ in. shatter index, the percentage of the coal charge that was fused and three tumbler indices the coal charge that was fused and three tumbler indices. The numerals placed along each curve indicate the number of days oxidation in air at 211 degrees F. The closer these numerals are spaced, of course, the lower the characteristic rate of oxidation of the coal.

For high-volatile coals that are not of two high original oxygen content—for example, Pittsburgh (No. 52) and Pond Creek (No. 53) coals—the coke strength remains fairly constant for a while, even rising somewhat, and then falls rapidly with increasing oxidation.

The low-volatile coals (Nos. 56 and 57) and the high-oxygen coal (No. 54) can consume relatively little oxygen before suffering serious impairment of coke strength. Their coking power is relatively sensitive to oxygen.

TABLE II

Change in Conditions Necessary to Triple Rate of Oxidation of a Coal

Coal	*A*	*B*
Description	Most oxidizable	Least oxidizable
Ratio of rates of oxidation under identical conditions	3	1
Conditions under which these two coals would consume oxygen at the same rate:		
1. Temperature of coal	60 degrees F.	84 degrees F.
2. Size of coal	1 in.	18 mesh
	¼ in.	48 mesh
3. Oxygen in air, per cent	3.5	20.9
4. Time since oxidation started		
Coarse coal	4 months	12 hr.
Fine coal	2.9 days	12 hr.
5. Oxygen consumed, per cent by weight of coal		
Coarse coal	8.72	.109
Fine coal	.909	.477

†Coke strength = 0.225 (1½ in. shatter) + 0.293 (¼ in. tumbler) + 0.352 (1 in. tumbler) + 0.202 (per cent fused) + 0.408 (100—friability). The average coke strength of all nine cokes from fresh coal = 100.

TABLE IV

Summary of Effects of Oxidation on Carbonization Yields

AVERAGE CARBONIZATION YIELDS OF NINE COALS

Effect of Volatile-Matter Content of Coals and Effect of Oxidation

Material	Values for fresh coal			Change caused by oxidation,* per cent		
	Range from		Ave.	Range from		Ave.
	High vol.	Low vol.		High vol.	Low vol.	
Coke	65.1	84.7	75.8	+ 3.5	—.22	+ 1.15
Tar**	9.7	2.0	5.5	—39.0	—15	—33.4
Gas	17.9	10.9	13.5	+ 9.1	—.5	+ 4.1
Gaseous Btu	3348	2664	3009	—Irregular—		— 2.6
Ammonia	—Constant—		.289	—Irregular—		+ 9.0
Liquor	4.9	1.3	3.0	—Irregular—		+27.1
Light oil	1.2	.5	.8	—Irregular—		+ 5.3

*Each coal oxidized just enough to cause a 15 per cent decrease in coke strength.
**Excluding High Splint coal.

Using Figure 4 as a master chart, we find the amount of oxygen required for each coal to reduce its coke strength by 15 per cent. This amount of oxygen (X_{15}) can then be used to measure the sensitivity of the coking power of the coal to impairment by oxidation. For example, Pittsburgh-bed coal (No. 52) of 39.3 per cent volatile matter requires 2.8 per cent oxygen to reduce its coke strength by 15 per cent, whereas Pocahontas No. 4 coal (No. 57, 18 per cent volatile matter) requires only 0.81 per cent oxygen to reduce its coke strength by 15 per cent. No special merit can be attached to the particular basis of comparison chosen—that is, the 15 per cent reduction in coke strength. However, when coals have consumed enough oxygen to cause this amount of change in carbonizing properties, considerable difficulty probably would be experienced in using these coals in an ordinary commercial oven. In the experimental work to date none of the oxidized coals were used in blends. Discussion of the specific effect of blending should await experimental results.

In Table IV the first three columns show the yields from fresh coal in pounds per 100 lb. of ash- and moisture-free coal and the last three columns the percentage of change in these yields when each coal is oxidized just enough to cause a 15 per cent decrease in coke strength. The yield of coke shows an average increase of 1.15 per cent of the value for fresh coal—the increase being greater for the high-volatile coals. The yields of tar are the most sensitive measure of extent of oxidation, showing on an average a decrease of 33.4 per cent of their values for fresh coal when the coals have been oxidized just enough to cause a 15 per cent decrease in coke strength. The yield of gas from the oxidized coals is up by 4.1 per cent. Gas analysis shows that this increase is due largely to CO_2 and CO. The average gaseous Btu. yield is 3009 Btu. per lb. of moisture- and ash-free coal and shows a 2.6 per cent decrease upon oxidation.

The yield of ammonia shows an average of 0.289 lb. per 100 lb. of coal for fresh coal. This corresponds to about 20 lb. $(NH_4)_2SO_4$ per ton of coal as received. For oxidized coal, this yield is up by 9 per cent. The yield of liquor on an ash- and moisture-free basis is up by 27.1 per cent for oxidized coal, and the yield of light oil is up by 5.3 per cent.

The detailed analyses of these various products of carbonization do not change greatly with the amount of oxidation to which these coals were subjected. For example, the analysis of coke including the percentage of sulphur, did not change appreciably with oxidation of the coal.

Table V shows the coking properties of each of the coals when it has been oxidized just enough to decrease its coke strength by 15 per cent. Reading from left to right, the coals are listed in the order of decreasing volatile-matter content. The first item, T_{15}, is the number of days oxidation (0 to ¼ in. coal in air at 211 degrees F.) required to cause this 15 per cent decrease in strength of coke, and X_{15} is the amount of oxygen consumed by each coal during this time of oxidation.

On the basis of the average coal, ten days oxidation under the standard conditions (1000 days at outside temperatures) was sufficient to cause the coal to consume 1.88 lb. of oxygen per 100 lb. of coal, and this resulted in a 15 per cent decrease in strength of coke. With two exceptions (coals 54 and 60) the number of days of oxidation is highest for high-volatile coals even though these coals do show the highest characteristic rates of oxidation.

The third item in the table is coke strength which, as explained before, is the weighted average of those five

Figure 4—Curves of coke strength vs. oxygen consumption show a general weakening of coke with increasing oxidation.

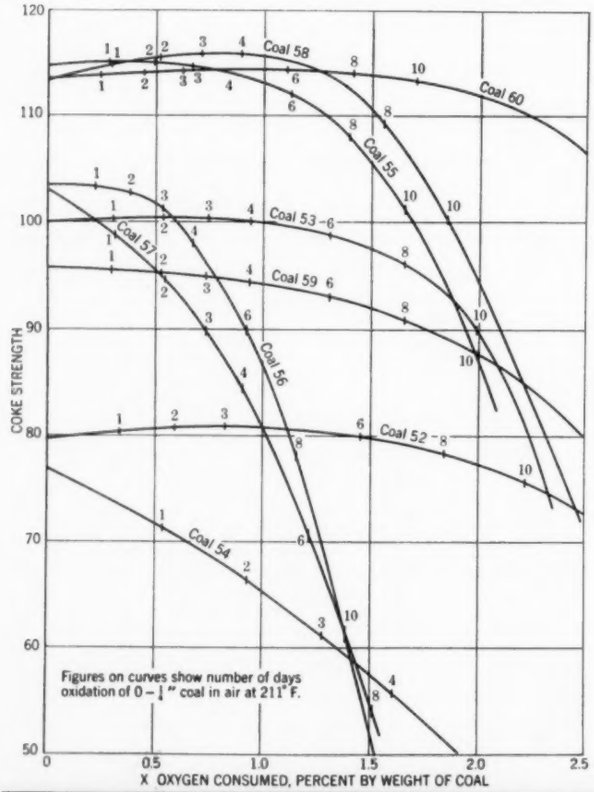
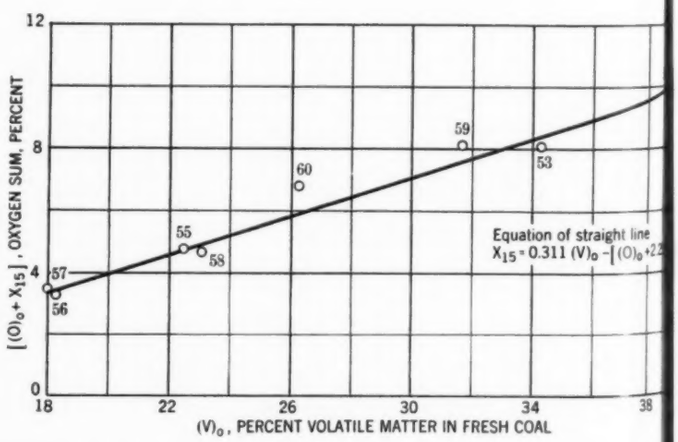

COKE STRENGTH
X OXYGEN CONSUMED, PERCENT BY WEIGHT OF COAL
Coal 58
Coal 60
Coal 55
Coal 53-6
Coal 57
Coal 59 6
Coal 56
Coal 52-8
Coal 54
Figures on curves show number of days oxidation of 0 – ¼ " coal in air at 211° F.

Figure 5—Coals falling above the line in this graph will form very weak coke upon carbonization.



measures of strength of coke which fall just below it in the table. The strength of coke from the oxidized coals ranges from 65.2 for High Splint coal (No. 54) to 97.7 for Sewell-bed coal (No. 55).

The ratio of the coke strength of oxidized coal to that of fresh coal is, of course, 0.85 in each case, because that is the basis of comparison chosen.

The item "percentage unfused" is the percentage of the coke, as taken from the retort, that passes through a 1-inch screen. It ranges from 2 for Pittsburgh-bed coal to 40 per cent for Lower Freeport coal. As will be seen later, fresh High Splint coal has an exceptionally high oxygen content for coking coals, and also the tests on Lower Freeport indicate it is somewhat abnormal. Disregarding these two exceptional coals we see that, in general, the "percentage unfused" is greater for the low-volatile coals. In other words, starting with fresh coals and oxidizing them progressively the first effect of oxidation noted on carbonization is poor fusion in the case of low-volatile coals. In the case of high-volatile coals, the fusion remains good but there is a general deterioration in strength of coke.

The hardness of coke is the percentage of the coke retained upon a ¼ in. screen after the tumbler test. Neither the hardness of coke from fresh coal nor the hardness of coke from oxidized coals shows large differences between different coals. With oxidation, on an average the hardness decreased by 17 per cent, while the coke strength was decreasing by 15 per cent.

The stability or the percentage of coke remaining upon a 1 in. screen after the tumbler varies in much the same way as hardness.

The friability or the percentage reduction of average particle size in the tumbler is more sensitive to oxidation of the coal than is coke strength, showing an average increase of 22 per cent.

The 1½ in. shatter index is not sensitive to oxidation of the coal, as its average value decreased by only 6 per cent, while the coke strength decreased by 15 per cent.

The apparent specific gravity of all cokes increased with oxidation of the coal, the average increase being 5 per cent.

The agglutinating value is a laboratory test on coal

TABLE V

Effect of Oxidation on Properties of Coke

(Coking properties when each coal has been oxidized just enough to decrease coke strength by 15 per cent)

Coal No.	54	52	53	59	60	58	55	56	57	Avg.
T_{15} days	2.2	13.5	11.0	12.6	19.7	10.7	10.8	6.3	3.4	10
X_{15} per cent of coal	1.0	2.84	2.14	2.42	3.01	1.96	1.76	.97	.81	1.88
Coke strength	65.2	67.7	85.0	81.3	96.5	96.3	97.7	88.0	87.5	85.0
Ratio[1]	.85	.85	.85	.85	.85	.85	.85	.85	.85	.85
Unfused per cent	21	2	3	5	40	18	14	18	19	15.5
Hardness (on ¼ in.)	59	43	56	52	68	63	61	56	52	57
Ratio[1]	.88	.70	.82	.78	.92	.85	.82	.85	.82	.83
Stability (on 1 in.)	23	37	48	41	65	59	59	52	49	48
Ratio[1]	.88	.86	.81	.77	.91	.83	.81	.83	.80	.83
Friability	77	77	66	66	49	52	52	59	54	61
Ratio[1]	1.06	1.12	1.22	1.14	1.30	1.37	1.41	1.25	1.14	1.22
Shatter index	63	75	84	84	93	88	90	87	90	84
Ratio[1]	.85	.98	.95	.96	.99	.93	.94	.92	.94	.94
Apparent specific gravity	.83	.83	.89	.90	.91	.96	.93	.88	.88	.89
Ratio[1]	1.05	1.01	1.09	1.06	1.15	1.01	1.07	1.01	1.02	1.05
Agglutinating value	1.7	5.6	5.1	4.6	5	3.6	3.4	4.3	4.2	4.2
Ratio[1]	.65	.67	.62	.58	.71	.68	.50	.83	.68	.66

[1]Ratio of value for oxidized coal to corresponding value for fresh coal.

that shows the crushing strength, in kilograms, of pellets made by carbonizing a small charge containing 15 parts sand or silicon carbide to 1 part powdered coal.[10] The agglutinating value showed a range from 8.4 kilograms for fresh high-volatile coal to 5.1 kilograms for fresh, low-volatile coal. Agglutinating value is as sensitive to oxidation as is the yield of tar, showing on an average of all coals a 34 per cent decrease, while the coke strength decreased by 15 per cent. Furthermore, the great value of the test as a measure of the extent of oxidation of a coal is shown by the fact that in the case of each individual coal a 34 per cent decrease in agglutinating value corresponds to roughly the same degree of impairment of coke strength. The author recommends more widespread use of this method among the coke-plant operators, especially those having difficulties due to use of stored coal or those wishing to store more coal.

In Figure 5 the values of the oxygen sum for the nine coals tested are plotted against the volatile matter of the fresh coals. "Oxygen sum" is the sum of $(O)_0$, the oxygen content of fresh coal (percentage of coal) plus X_{15}, the amount of oxygen consumption (percentage of coal) required to decrease the coke strength by 15 per cent. The points fall along a straight line. If the value of the oxygen sum of a given sample of oxidized coal falls above the line in Figure 5 the coal will form very weak coke upon carbonization; that is, the coke strength will have been reduced by more than 15 per cent.

This figure shows, for example, that Pittsburgh-bed coal (No. 52) with an original oxygen content for fresh coal of 7.0 per cent, can consume 2.8 per cent oxygen before its oxygen sum is up to the line value of 9.8 and the strength of coke is decreased by 15 per cent. In contrast, fresh High Splint coal of about the same volatile-matter content has a relatively high oxygen content (8.7 per cent) so that it can consume only 1 per cent oxygen before its oxygen sum is up to the line and its coke strength is decreased by 15 per cent.

Thus it is indicated that coals of high original oxygen content not only consume oxygen at a relatively high rate (Figure 2), but also their coking power is destroyed by relatively little oxygen. The slope of the line in Figure 5 shows that the higher the volatile matter content of a coal the higher the original oxygen content can be and the coal still possesses good coking and storing qualities.

If the proximate and ultimate analysis of a new coal is known, a rough prediction of its relative storing properties can be made, using Figures 2 and 5. There is considerable promise that if more information can be obtained by oxidizing and carbonizing more coals, an accurate prediction of storing properties of a coal can be made using only the results of standard tests on the fresh coal.

SUMMARY AND CONCLUSIONS

Other conditions being equal, the length of time that a coal can be stored in air without serious impairment of its coking properties depends on two different properties of the coal: (1) its characteristic rate of oxidation —that is, its rate of consumption of oxygen under standard conditions; and (2) the amount of oxygen that the coal can consume without loss of coking power —that is, its sensitivity to oxygen. High-volatile coals, in general, show high characteristic rates of oxidation, but unless the coals are exceptionally high in oxygen content also, this high rate of oxidation is often more than compensated by the fact that these coals can consume relatively large amounts of oxygen without harm to their coking power. Conversely, low-volatile coals show relatively low characteristic rates of oxidation, but often their coking power is destroyed by relatively little oxygen. High oxygen coals not only show high characteristic rates of consumption of oxygen, but in addition their coking power is destroyed by relatively little oxygen. Among the coals tested there is a ninefold range in the time of oxidation required to impair the coking power seriously. Storage conditions are so vitally important that there is considerable promise that care in storage can overcome the differences in storing qualities of the different coals. The author makes two recommendations: (1) That coke-oven operators measure the effect of various methods of storage upon the percentage of oxygen in the air inside large piles of coal, and (2) that they use the agglutinating-value test as a measure of the extent of oxidation of stored coking coals.

DISCUSSION

PRESENTED BY

D. P. FINNEY, *Assistant General Superintendent,* Charge of Coke Plant Operations, Carnegie-Illinois Steel Corporation, Clairton, Pennsylvania.

F. A. HAGEDORN, *Superintendent,* Coke Plant, Interlake Iron Corporation, Chicago, Illinois.

J. D. PRICE, *Superintendent,* By-Product Coke Plant, Colorado Fuel and Iron Corporation, Pueblo, Colorado.

D. P. FINNEY: We, at Clairton, have compared several of the important factors that were developed in Dr. Schmidt's investigation with actual performance of storage coal in our ovens and found similarities that were very satisfactory. An important factor not mentioned in Dr. Schmidt's paper which is extremely important to coke plant operation is the fact that coke made from high volatile coal which has been in storage long enough to materially effect its agglutinating power cannot be pushed from coke ovens. We have found it necessary to mix as high as 50 per cent of fresh coal with old stock coal in order to produce a coke that would push.

F. A. HAGEDORN: The facts brought out in Dr. Schmidt's paper, while produced under laboratory conditions, indicate what is to be expected in a practical way from the oxidation of coal.

We have experienced in a practical way a number of times the bad effect of oxidized coal on coke oven practice. At various times we have accumulated coal from

a particular mine and have stored this coal pending future consumption. It has been our experience that when this coal is stored too long, heating begins to take place in the pile itself, and the coal, when charged in the ovens, produces the effect outlined by Dr. Schmidt. The degree of unfavorable reaction depends, of course, upon the age of the coal and the compensatory factors introduced to nullify the effect of aging.

Oxidized coal is generally thought of as resulting from the storage of coal in large piles and for a long time. However, this is not necessarily true, as we have experienced unfavorable results from oxidized coal which was apparently fresh. We first experienced this condition in the late summer of 1933. During 1932 and early in 1933, coking operations, as well as coal mining, were almost at a standstill and practically all of the mine faces were lying idle, yet exposed to oxidation in the mine. In the fall of 1933, when expanding operations throughout the country demanded more coal, these idle faces were mined and the coal which we received, while fresh from the mine, was noticeably oxidized, to the extent that it caused us pushing trouble in the ovens and later hot spots in the storage piles themselves. This condition was again experienced in the fall of 1940, when a large expansion for coal undoubtedly caused operators to open up new faces, so that spotty shipments were received containing oxidized coal.

It is important to the coke oven operator that he recognize the effect of coal oxidation, in order to minimize his operating troubles, along with producing a better product from his carbonization process.

J. D. PRICE: By way of preface to my remarks, there are two points which should be mentioned: First, not having had an opportunity to review Dr. Schmidt's paper, my remarks are based on previously published papers of the doctor's. Second, the results which I will discuss and the figures which I will quote have been secured with Colorado coals. These coals do not behave the same as do eastern coking coals under similar treatment in the coke oven. Therefore any results which we have obtained should not be taken as a criterion of what may be expected from similar treatment of eastern coals.

While Colorado has a large variety of coals, only a limited number are suitable for coke production, and these, without exception, are high volatile, low rank bituminous coals, ranging from 30 to 42 per cent volatile matter. Our coke produced is therefore weak as compared with eastern cokes, having a tumbler index (stability) of 25 to 30 as compared to 55 to 60 on the coke produced in the eastern and mid-western sections of the country. Because of this, we are constantly endeavoring to find means of improving the strength of our coke; oxidation is one possibility which we have not overlooked. Our interest in oxidation is therefore of a different nature from that of the doctor's. He shows us the harmful effects of oxidation during storage, etc., upon the physical properties of the coke. We are attempting, through other means of securing an increase in the oxygen content of the coal, to secure a beneficial action on the coke strength. As may be expected, the results we have obtained from a straight oxidation of our coking coal have been negligible. An oxygen absorption of 12 per cent, that is, an increase in oxygen content from 6.6 to 7.4 per cent, secured by atmospheric oxidation of the coal, showed but little effect. However, when the increase in oxygen content exceeded 15 per cent, the decrease in stability is quite apparent. For this reason, storage of our coals for periods greater than 30 days is impractical. The behavior of our coal closely parallels the results obtained by Dr. Schmidt on Pittsburgh bed coals; in fact our coke is quite similar to coke made from 100 per cent of that high volatile coal.

We have, however, been able to secure an improvement in our coke strength with other high volatile coals blended into the mix. While neither the stability factor as determined by the tumbler test nor the shatter index show a great improvement by this blending yet there is an improvement in the size of the pieces of coke, in the porosity and in its behavior in the blast furnace, all of which does make blending of decided value to us. And in addition we are able to select low ash coals for blending which also is a desirable feature. Two such blends are used, the first consisting of about 90 per cent of a fairly heavy coking coal with 6.6 per cent oxygen content plus 10 per cent of a higher volatile non-coking coal of 13.8 per cent oxygen content, giving a mixture of 7.58 per cent oxygen. We will refer to this mixture as the 9010 mix. The second blend consists of 60 per cent of the dense coking coal plus 40 per cent of a semi-coking coal with a 10.9 per cent oxygen content, giving a mixture containing 8.38 per cent oxygen and which we will refer to as the 6040 mix.

Referring now to the chart, we have, on the upper portion, curves representing variations in the stability factor of the cokes produced from coals with varying oxygen content factor. On the lower portion of the scale the shatter index factor replaces the stability factor on the horizontal scale. The oxygen factor, shown on the vertical scale, is obtained by dividing the per cent oxygen content of the original coal into the oxygen

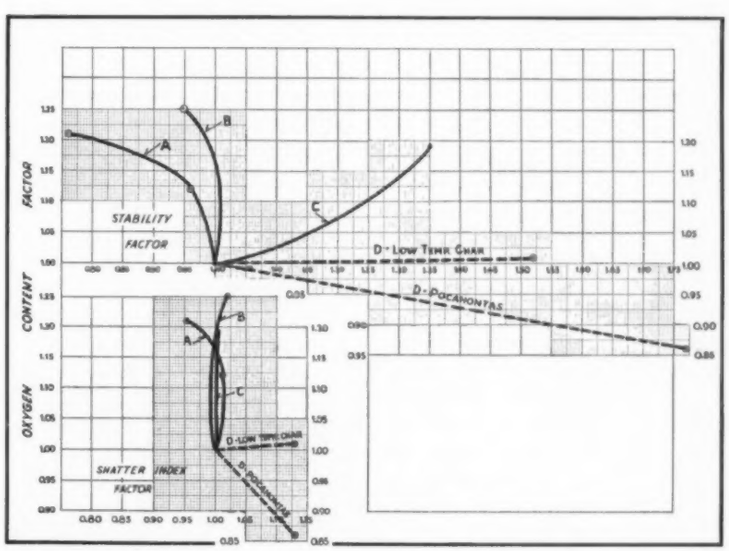


Chart showing variation of stability and shatter index of coke from coals of varying oxygen content.

content of the blend or oxidized coal. The stability factor is determined by dividing the per cent remaining on a one-inch screen from the tumbler test on the original coal into the same figure secured from tests on the blend or mixture. The shatter index factor is secured in the same way; but by substituting the percentage remaining on a 1½ in. screen after shatter testing for the tumbler test figures. Thus we see the curve A representing the relationship between the oxygen and stability factors of oxidized high volatile coals. Here is shown a slight decrease in stability factor to 0.96 with an oxygen factor of 1.12 and a decided further decrease in stability to 0.76 with an oxygen factor of 1.21. The shatter index shows a slight improvement to 1.014 and then a more pronounced decrease to 0.95 with the two oxygen factors respectively. These figures check closely with data given in a previously published paper of Dr. Schmidt's representing results secured on a Pittsburgh seam coal.

The curves representing the two blends of coal are shown as B on the chart. The 9010 blend, with an oxygen content factor of 1.13, shows a stability factor of 1.004 and a shatter index factor of 0.996. The 6040 blend, with an oxygen factor of 1.25, shows a stability factor of 0.947 and a shatter factor of 1.022.

In a further study of the effect of oxygen content upon the physical properties of our coke, a series of tests was conducted in which a portion of the original coal, showing an oxygen content of 6.25 per cent was oxidized to various oxygen contents considerably higher. Two such oxidized coals were selected, one with an oxygen content of 8.68 per cent and one with an oxygen content of 12.07 per cent and blended in the proportion of 80 per cent original coal and 20 per cent oxidized coal. In this way blends were obtained showing oxygen factors of 1.08 and 1.19. The stability factors of these blends indicate a pronounced increase in strength as the oxygen content increases. As shown in C on the chart, gains in stability factor of 1.21 and 1.35 are secured for the two blends, respectively. The shatter index curve shows practically no change. It is planned to continue this work in an effort to determine the shape of the stability curve, for at some higher point in oxygen content, whether secured by the blending of still higher oxygen portions or by the use of greater amounts of the oxidized coal in the blend, there must be a change in the general trend of this curve.

But these results are not sufficient for us. With the use of 20 per cent Pocahontas in our mixture, the stability factor, as shown in D, is increased to 1.77, and the shatter factor to 1.13, this with an oxygen factor of 0.86. At a delivered price of $12.00 to $14.00 for Pocahontas, its use is out of the question and we must make our own low volatile substitute. This is now being done on a pilot plant scale by low temperature carbonization, without oxidation, of some of the original coal in a single retort, and the blending of about 20 per cent of this with the original coal. Preliminary tests have indicated an increase in stability factor to 1.53 and shatter factor to 1.13; how much nearer the stability can be made to approach the Pocahontas results remains to be determined.

I realize that I have opened up a number of controversial points which I will not attempt to cover. First, it is quite possible that the benefits which we have obtained from the use of different coals in the mixture or from the use of blends with highly oxidized portions of the original coals are due to some other and entirely different cause than the variation in the oxygen content of the coals and that this relationship is purely coincidental. Second, a number of the tests, the results of which have been shown on the curves, have had results so close as to be within the bounds of experimental error. This is especially true of the shatter test results shown. Third, the oxygen content of the various coals as tested was determined by the "difference" method and its correctness is also subject to question.

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BALLENGER *and* RHEA

(*Continued from page 63*)

The use of wound rotor induction motors with flywheels is more common on the wide hot strip mills than on the narrow due to the higher loads obtained. This is particularly true of the broadside stands.

The percentage of time the first stand is working is in the order of two per cent and of the fourth roughing stand about 10 per cent. This means that from 90 to 98 per cent of the time these stands are idle and the windage and friction losses of such equipment must be charged against the cost of rolling the steel.

The standby losses are very much less if synchronous motors are used to drive these roughing stands. If the peak loads are not objectionable and they usually are not on a system large enough to handle a hot mill, and the pull-out is adequate to avoid having the motor trip off due to overloads, the installation of synchronous motors not only mean less first cost but also lower standby losses which results in less kilowatt hours per ton of steel rolled.

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Our catalog makes it easy for you to select the wires that will take the trouble spots out of your wiring system. It shows many of our 118 maintenance-eliminating standard constructions and lists typical applications in which they are used. Send for a copy and don't hesitate to ask for samples if you want to get the inside story on *permanent insulation*. Rockbestos Products Corporation, 988 Nicoll St., New Haven, Conn.

Also refer to McGraw-Hill Electrical Buyers Reference

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Rockbestos 600 Volt All-Asbestos Power and Rheostat Cable — No. 18 AWG to 1,000,000 CM — one of 118 different permanently insulated wires.

EXPENDITURES IN 1941 FOR STEEL INDUSTRY'S NEW EQUIPMENT TO BE NEAR $300,000,000

▲ To meet the expected expansion in the nation's requirements for steel for defense and other purposes, steel companies plan to spend more than $282,000,000 for new productive equipment during 1941, according to information furnished to the American Iron and Steel Institute by 160 companies in the industry.

The expenditure of this sum is expected to gear the industry for increased production during the defense emergency, although some of the new equipment will not be available until next year. With the sum budgeted for this year, the sum spent or about to be spent for new equipment by the industry since the beginning of 1935 is brought to a total of $1,390,000,000.

From the beginning of 1935 to the end of 1940, steel ingot capacity was increased from approximately 78,000,000 net tons to more than 84,000,000 net tons, and further increases will be effected this year with the sums provided for such enlargement. Productive capacity for pig iron, coke and finished steel is also being increased.

To forestall any bottlenecks in the various phases of steel production, actual expenditures in 1940 for new equipment were sharply increased and totaled $25,000,000 in excess of the amount budgeted at the beginning of the year, before the defense program was expanded, the survey showed.

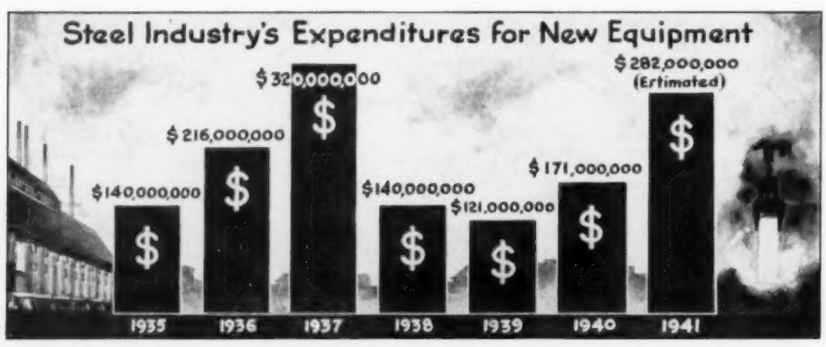
The total actually spent was over $171,000,000, whereas expenditures contemplated at the beginning of the year had been estimated at only $146,000,000. No small part of that increase was due to the building of new electric furnaces not scheduled at the beginning of the year.

This year's program covers the entire range of steel mill productive facilities and provides additional coke, pig iron and steel ingot capacity as well as equipment for many varieties of rolled and finished steel. Where potential bottlenecks have been located by individual companies, new equipment is being installed.

The breadth of the construction program is shown by the fact that 15 companies are contemplating expenditures for new rolling mills; 29 companies for modernization or enlargement of existing rolling mills; 23 companies for new wire drawing facilities; 22 companies for new cold finishing equipment; 40 companies for new heat treating equipment.

Fourteen companies plan to install new blast furnace equipment and several other companies propose to build new blast furnaces, open hearth furnaces, and coke ovens. Twelve companies plan new electric furnaces to increase output of alloy steels.

Expenditures for new equipment since 1935 will be $1,390,000,000 by the end of 1941. A concentrated effort of expansion has increased the nation's steel capacity to 84,152,000 net tons, the highest figure of capacity ever recorded in the history of the steel industry.



SURVEY SHOWS PIG IRON CAPACITY TO INCREASE

▲ At the end of 1941, according to the report made to the President by Gano Dunn, blast furnace capacity will be 59,817,710 tons compared with 57,609,590 tons at the end of 1940, an increase of 2,208,120 tons.

Additions during 1940 were: American Rolling Mill Company 107,520 tons, Antrim Iron Company 4480, Bethlehem Steel Company 246,720, Ford Motor Company 56,000, Otis Steel Company 400, Republic Steel Corporation 249,200, Shenango Furnace Company 23,280, Tennessee Products Corporation 15,160, United States Steel Corporation 1,322,900, and Youngstown Sheet and Tube Company 103,740.

Decreases during 1940 were: Alan Wood Steel Company 10 tons, Colorado Fuel and Iron Company 47,250, Jones and Laughlin Steel Corporation 181,440, Pittsburgh Coke and Iron Company 170, Pittsburgh Steel Company 1270 and Sheffield Steel and Iron Company 13,040.

This year, the American Rolling Mill Company will add 300,000 tons, Bethlehem Steel Company 780,000 tons, Colorado Fuel and Iron Company 245,000 tons, Globe Iron Com-

pany 4500 tons, National Steel Corporation 550,920 and Tennessee Coal, Iron and Railroad Company 327,700.

American Rolling Mill Company is now constructing a $5,000,000 blast furnace with a daily capacity of 1000 tons of pig iron at the Ashland, Kentucky, plant. A railroad storage yard capable of holding 200 cars and a 400,000 ton ore storage equipped with ore bridge and car dumping equipment is included in the construction. No coke ovens are contemplated at the present as the company will continue to purchase coke from outside sources already established. Operation of two other blast furnaces operated by the company at Ashland in conjunction with its open hearths and continuous rolling mill will be continued.

National Steel Corporation's subsidiary Weirton Steel Company has received a certificate of necessity from defense officials for its expansion program which is now under way at Weirton, West Virginia. The new blast furnace, which will add 320,000 tons per year to the present pig iron capacity, will be complete with stoves, gas and air mains, gas washing, electrical and other equipment. Forty-five new coke ovens are being constructed adding approximately 400,000 tons to the annual coal carbonizing capacity of the coke plant. A 200 ft. extension of the ore yard and a new ore bridge, gas cleaning equipment including two complete precipitators, a building extension to house a new turbo blower, an extension to the pump house, a new ladle building and crane, a new building in connection with the converter together with a 120 ton crane and other equipment, and the addition of a boiler and changes in existing boilers to permit the burning of gas from the new blast furnace are among the many facilities to be included in the $10,000,000 expansion program.

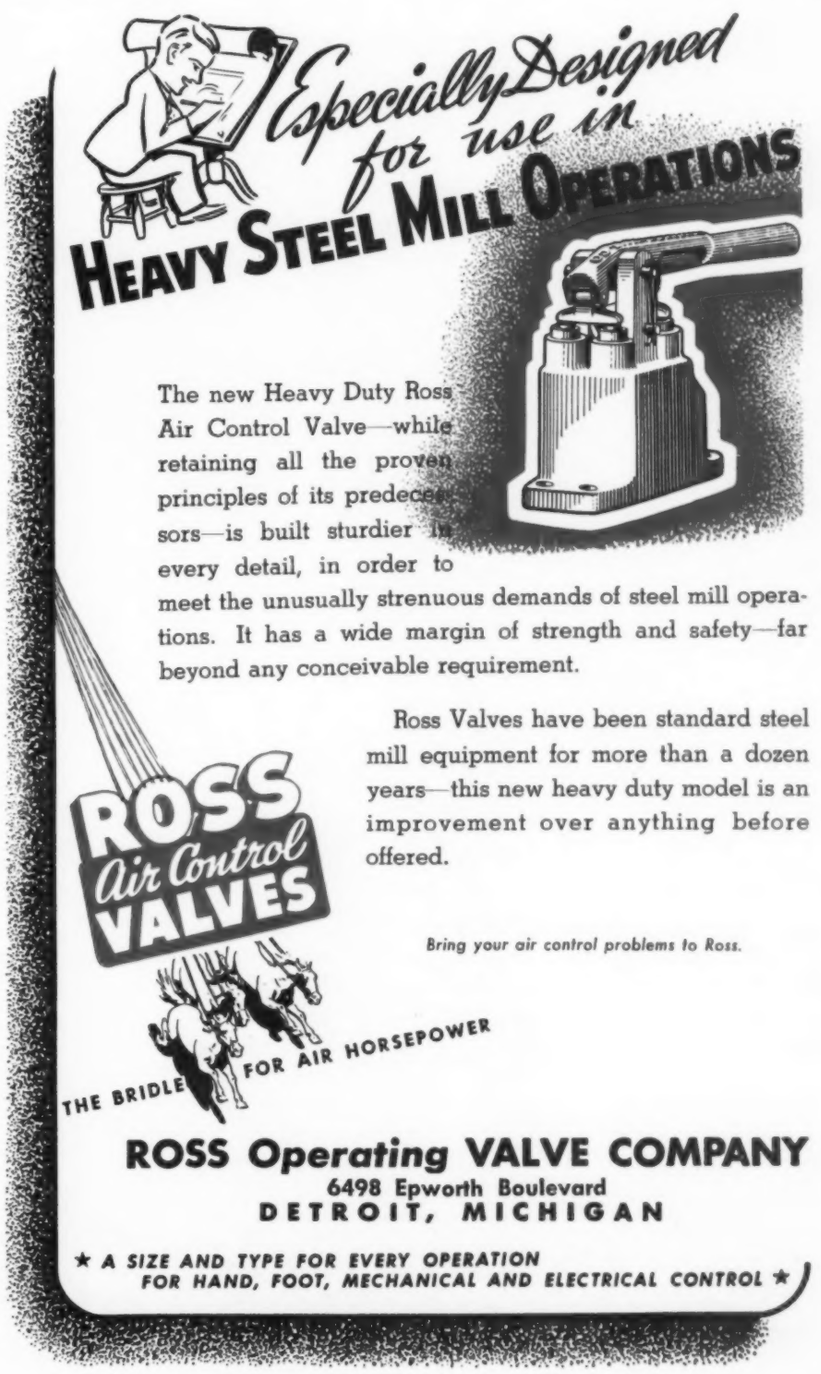
Tennessee Coal, Iron and Railroad Company has blown out No. 5 blast furnace at Fairfield for complete overhauling and repairs. It has been in continuous operation since 1933, producing an estimated total of 1,068,000 tons of pig iron. Except for this stack, all others in the district are blowing. As a result of this shutdown of No. 5 stack, one open hearth unit at Ensley and also one at Fairfield works will cease melting.

Great Lakes Steel Corporation has placed an order for the installation of two Peabody Engineering Corporation's scrubbers for cleaning and drying blast furnace gas; one each for the Detroit and Buffalo plants. One unit will modernize a scrubber now in service, the other will be located in a column that has been unused.

Bethelehem Steel Company has also contracted with the Peabody Engineering Corporation for the improvement of two blast furnace gas washers for its Lackawanna plant.

DEVELOP IGNITRON TUBE FOR RESISTANCE WELDER

▲ A new ignitron tube, type GL-415, for resistance-welder control, utilizing a unique water-cooling system, has been announced by the General Electric Company. The new tube depends for its cooling upon a special clamp into which it is fitted, rather than upon the built-in water-jacket con-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HEAVY STEEL MILL OPERATIONS
The new Heavy Duty Ross Air Control Valve—while retaining all the proven principles of its predecessors—is built sturdier in every detail, in order to meet the unusually strenuous demands of steel mill operations. It has a wide margin of strength and safety—far beyond any conceivable requirement.
Ross Valves have been standard steel mill equipment for more than a dozen years—this new heavy duty model is an improvement over anything before offered.
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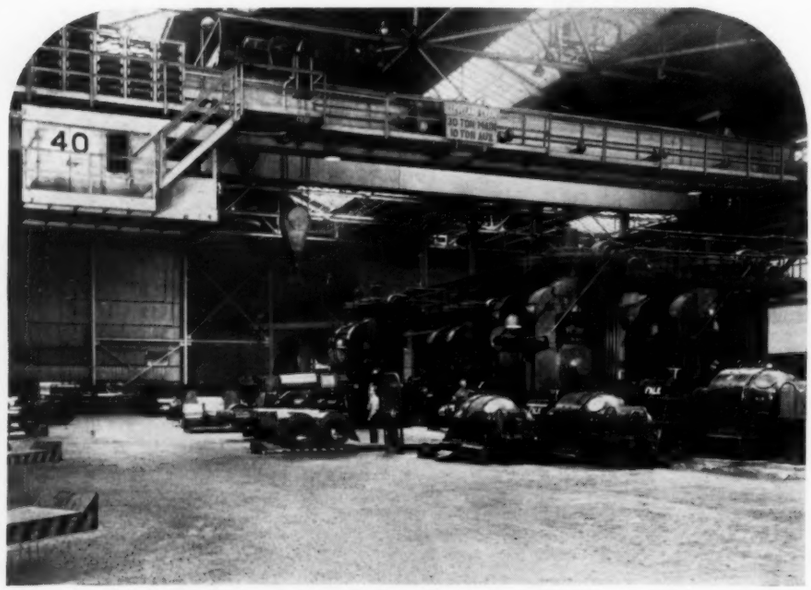
struction formerly used. Consisting of a brass block with water passages, the clamp not only serves as a cooling medium but also as the cathode connection. Since there are no water connections to the tube itself, removal an nections to the tube itself, removal and replacement of tubes may be made easily and quickly.

Ability to pass high-peak currents makes these ignitron tubes particularly suited for controlling the current of resistance-welding machines. Their sturdy metal construction, noiseless operation, and absence of moving parts, contribute to long life with a minimum of "down" time.

A pair of the tubes is capable of controlling 265 kva. of resistance-welding load on a 5½ per cent duty cycle. They can be used at reduced rating with air cooling, when desired. With suitable control, the tubes can be used also for accurate, short-time welding.



30 ton, 80'—0" span Cleveland all-welded Crane with 10 ton auxiliary hoist in a tinplate mill.

THEY BUY 5 TO 20 AT A TIME

When mills buy Cleveland all-welded cranes in lots of 5, 10, and 20 at a time, they must have features that are outstanding.

Cleveland Cranes are different from all other cranes because all parts are welded including the girders. There is no sag from rivet slippage to cause misalignment and abnormal wear. Because of the special shoulder construction girders remain square with the end trucks for the life of the crane.

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ALL-WELDED OVERHEAD TRAVELING CRANES
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FOLLANSBEE PRODUCING SPECIAL ALLOY STEELS

▲ Follansbee Steel Corporation is utilizing some of the excess open hearth capacity at its Toronto, Ohio, plant for the production of special alloy steels. At the same time, it is helping to alleviate the current shortage of electric furnace melting capacity, usually devoted to making such grades but now largely earmarked for important defense production. Within the past few weeks, the company has booked orders for more than 200,000 tons of semi-finished alloy steel to be delivered as ingots, blooms and billets, and sheet bar.

Produced in the company's small, closely controlled open hearth furnaces, this steel approaches electric furnace quality. A 1000 ton steam hydraulic press is used to forge ingots to blooms at the Toronto plant.

NEW DUST-PROOF OILER HAS REMOVABLE FILTER

▲ A new, visible, unbreakable, dust-proof oiler has been announced by the Trico Fuse Manufacturing Company. This new oiler is intended for all applications of gravity feed type oilers where the dust-proof feature is desirable. No foreign matter to destroy the life and accuracy of bearings,

especially on high speed precision machinery, can pass the 100 mesh brass screen and felt filter.

A unique feature is the removable filter that can be extracted for cleaning in less than five seconds without tools or waste of time. Unscrew dome and remove filter, that's all. If it is important that dust and dirt shall not reach the bearing, then it is likewise important that the filter be easily

extracted for cleaning without disassembling the oiler to get at the filter. The dangers of neglect and clogging, which result in costly failures, are eliminated.

The oiler is mounted at the top of the part to be lubricated and any predetermined number of drops of oil per minute can be obtained by a simple adjustment of the needle valve. The shut-off lever at the top, when in a vertical position, as shown, feeds oil, and when tilted to the side, stops the flow.

DOUBLE ROD CAPACITY OF MARYLAND ROD MILL

▲ Bethlehem Steel Company is installing a second group of finishing stands, and additional coiling, conveying and storage facilities in the continuous high speed rod mill at the Maryland plant of Bethlehem Steel Company. The rod mill is now equipped for rolling four strands of rod at one time. The extension roughly doubles the rod making capacity of the mill, increasing it from 500 to approximately 1000 tons of No. 5 rod per 24 hr. day.

The mill was built nearly three years ago and though at the outset it rolled only two strands of rods, it was designed for ultimate four strand operation. A second rod finishing mill has been installed.

CONCENTRATED RESEARCH DEVELOPS NEW GREASES

▲ Two new lines of lubricating greases for ball and roller bearings, have been developed by the Gulf Refining Company. The new greases are backed by a number of years of concentrated research by Gulf's technologists.

One, designated Gulf anti-friction grease, is recommended for heavy duty service. The other, Gulf precision grease, is recommended for lighter duty and higher speeds. Both have a high melting point and are specially prepared for greatest resistance to oxidation and separation.

Gulf's newly developed method of compounding, employing special high pressure kettles and mixing methods, produces these greases with a relatively smooth, non-fibrous texture, which gives a true picture of their consistency.

TEXAS LOCATION CHOSEN FOR NEW TIN SMELTER

▲ A $3,500,000 government owned tin smelter designed to smelt low grade Bolivian ore, bought by the government for its strategic stock pile, will be erected at Texas City, Texas. The plant is to be built and operated for the government by a New York subsidiary of a Dutch company experienced in smelting operations in England and the Netherlands East Indies. The firm will receive a fee of 4 per cent on construction costs and an operating fee of 1 per cent of the value of the tin output.

Texas City, across the bay from Galveston, Texas, was selected because of the gift of a valuable site by the Texas City Terminal Company, the availability of gas for fuel and of hydrochloric acid from a nearby re-

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finery, good terminal, warehouse and port facilities. Government officials indicated that the site selected was strategically located for defense purposes.

The smelter will be built by the Tin Processing Corporation, a subsidiary of N. V. Billiton Maatschappi, and will have an annual capacity of 50,000 tons of tin concentrates, or 18,000 tons of fine tin. In a recent report the Bureau of Mines stated that stocks of tin in the United States were sufficient for about fifteen months at the current rate of demand.

NEW FLOOR MANIPULATOR WORKS INDEPENDENTLY

▲ One of the most recent developments in handling and manipulating forgings under the steam hammer and press is the auto floor manipulator made by Edgar E. Brosius, Inc. This machine is an outgrowth of the Brosius auto floor charging machine in that it travels about as an independent unit under its own power and can work freely at any point around furnace, press or hammer, unrestricted by tracks.

This type machine is built in various sizes. The smallest one can handle loads up to 2000 lb.; the intermediate machine handles a maximum load of 6000 lb.; and the largest up to 15,000 lb.

All motions, except floor travel, are hydraulic, thus affording great flexibility during operation. These motions include tilting or raising of the peel, opening and closing of the tongs shoes, rotation of tongs head, and steering. The tractor motion is actuated by an electric motor which is mounted in the tractor unit.

All hydraulic motions are actuated by an oil pump driven by a pump motor mounted on one side of the machine.

Power for both motors is received from a flexible cable attached to a rotating collector mounted at the top of the collector mast. This design makes the machine independent of tracks and affords maximum freedom to the operator in performing his job.

Extreme mobility is a cardinal feature owing to the tractor unit swinging 180 degrees and thus permitting the machine to turn on its own wheel base. This feature makes the machine highly adaptable to operation in restricted areas.

PLASTIC CHARTS FOR RECORDING INSTRUMENTS

▲ An improved design in recording instrument charts made for continuous re-use has been developed by the Permochart Company. Permocharts, made of plastic, can be constantly reused, as the previous day's ink record is easily removed from its surface with a damp cloth. Designed especially for industries such as steel, smelting and metal refining industries where large numbers of recording instrument charts are used, as Permocharts are said to reduce chart costs by 80 per cent or more.

The new Permocharts will not curl, are non-flammable, and are oil, gasoline and grease resistant. Because each chart is in use over a long period

Complete Control from One Position Contributes to

High Output of Rolls from
FARREL ROLL GRINDERS

This illustration of the control panel of the Farrel Heavy Duty Roll Grinder shows at a glance how *centralized fingertip control* contributes to the high output of accurately ground and flawlessly finished rolls for which this machine is noted.

Without moving from his station, the operator may reach any control button or rheostat with a single movement of the arm. On a fully enclosed panel at the operator's right are located all push buttons and rheostats for the control of the several motors, with the exception of the rapid wheel feed, which is located on the operator's left next to the indexed handwheel for hand feeding of the grinding wheel. For ease in setting up a roll in the grinder, additional push buttons for controlling the headstock motor are mounted on the headstock.

This complete *centralized fingertip control* reduces movement of the operator to a minimum; his entire attention and energy may be devoted to the work, thus assuring a continuity of output and a high daily *production with precision* which keeps roll refinishing costs at a minimum.

For full particulars of additional features which combine to give the Farrel Heavy Duty Roll Grinder its record for smooth, vibrationless performance, superior finish and high output, let us send you a copy of Bulletin No. 111. This booklet contains complete specifications and illustrated description of all features.

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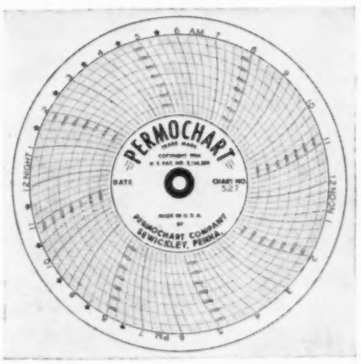
of time, chart centers are now reinforced to prevent deterioration, even from holding devices using sharp projections. The printing and laminating



of Permocharts have been improved so that the charts are now clearer and cannot separate at the edges. Each chart is guaranteed for daily use over a period of two years under normal working conditions. Permocharts are made for all types of recording instruments which use circular charts. For applications where it is necessary to save chart records, the Permochart Company has established a microfilm photographic system for recording and filing.

NICKEL MANGANESE STEEL GEARS RESIST HEAT

▲ Manganese steel gears, like those shown, have been used for thirty years for driving rolling mill tables and are still widely employed for their tough resistance to breaking stresses and abrasion.

The experience of one Pittsburgh district steel mill operating man was recently described by him as follows:

"Gears made of 13 per cent manganese steel possess remarkable toughness and wear resistance. The teeth may bend under excessive loads but will not break; and the tooth face becomes work-hardened and polished from continuous usage.

"Comparative service trials, extending over three years, have demonstrated their ability to withstand higher impact and to outwear any of the types of gears we use at these works; hence, manganese steel table gears are employed throughout instead of either cast or forged gears of any other kind where the operating conditions are exceptionally severe.

"Inasmuch as Hadfield or 13 per cent manganese steel is not economically machineable by cutting tools under ordinary conditions, the table gears made of this steel are ordered from the foundry, ground to finished sizes in bores, keyways and hub faces, that is, ready for installation."

In some mills there has been a tendency to abandon their use because of the characteristic of austenitic manganese steel to lose its "temper" under temperatures higher than 650 degrees F. applied for any considerable period. Such heating is sometimes necessary in shrink-fitting the gears to their shafts, and while this is feasible even with standard manganese steel if care is taken to control the temperature precisely, the job requires closer superivision than is always available. Consequently,

AMCO PIT installations usually produce 100% greater heating capacity *in the same space* . . . a record typical of AMCO performance. In times like these, when increased industrial capacity is so essential, AMCO PIT FURNACES fittingly solve the problem, since they require no additional floor space! Moreover, AMCO PITS give increased tonnage with less fuel consumption and more uniform heating . . . *every heat alike, every ingot alike!*

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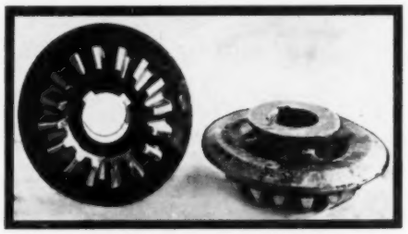
there is some danger of standard manganese steel gears cracking because of a greater heat being used than the steel will stand without deterioration of the grain structure.

However, it has become a matter of common knowledge latterly that with some adjustment of carbon content and the addition of about 4 per cent nickel to the formula for 13 per cent manganese steel gears, the metal has a greater ability to resist changes in grain structure that result in standard manganese steel from overheating as in a shrinking-on process. A nickel-manganese steel bar with no more than a 1 in. metal section will, under atmospheric cooling only, return to a satisfactory, tough, austenitic state even after heating to the temperature 1900 degrees F., which is the usual quenching temperature for standard manganese steel. It is true that the greater the metal section, the lower is the temperature to which nickel-manganese steel can be heated without harm, but in the case of table gears where the metal sections seldom exceed 2 in., they can be heated to as much as 900 degrees F. without thought of any serious adverse effect.



Properly made nickel-manganese steel castings have the same toughness and work-hardening property as the standard metal, so with the added merit of relatively good heat resistance, rolling mill maintenance men can take full advantage of the established economy of manganese steel gears in points of wearing life and resistance to torsional stress.

During the past few years hundreds of these nickel-manganese steel table gears have been installed by mills in the Pittsburgh district, and they have reported no instances at all of breakage consequent to heating for shringing.

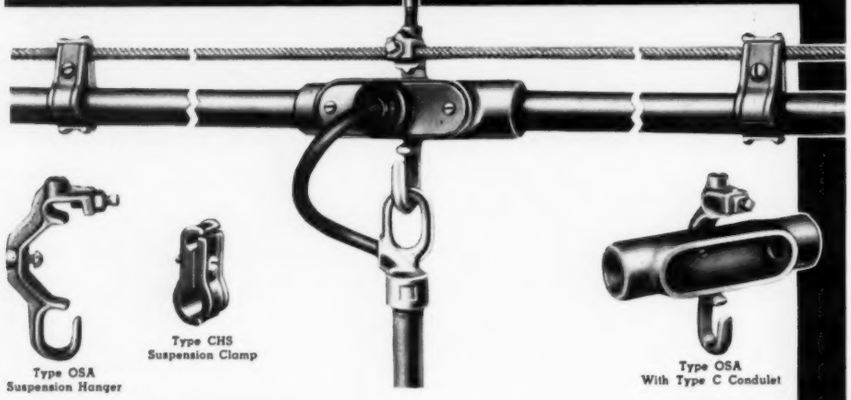
(*The foregoing material was prepared by J. A. Brandenburg, Sales Engineer, American Manganese Steel Division of the American Brake Shoe and Foundry Company, Pittsburgh, Pennsylvania.*)

NEW LITERATURE

▲ A review by sales executives of a recently published book on the subject of "Sales Engineering" by Bernard Lester is recommended, as the book contains many features which should prove helpful.

The book gives a very well defined and logical program of procedure of conducting a sale, and it outlines the methods of cooperation and the ideas of mutually helpful results that should be considered by the salesman in mapping out his program. The subject matter includes many actual sales experiences and in general is a very interesting and helpful guide for the younger salesman. In addition, the more experienced men will find Mr. Lester's views on the subject of sales engineering well worth while. This book was published by John Wiley and Sons, Inc., New York, New York.

CROUSE-HINDS
Type OSA Suspension Fixture Hangers



In industrial buildings where it is necessary to suspend lighting fixtures at some distance below the ceiling or roof structure, span wires may be stretched across the areas as the supporting means. Type CHS clamps and type OSA suspension hangers are used for hanging the conduit, the fixture outlet Condulets, and the fixtures from the span wires.

When installed, type OSA suspension hanger is attached to the fixture outlet Condulet (Form 7 Obround) and hooked over the span wire, thereby supporting both the Condulet and the fixture. The lower hook which supports the fixture is so shaped that the fixture and stem assembly cannot be accidentally disconnected. The span wire is clamped in the upper hook by a set screw with lock-nut. Additional support may be obtained by use of a ⅜-inch rod screwed in the upper end of the OSA hanger and attached to the ceiling or roof structure.

Type CHS clamp grips both the span wire and the conduit. It is not necessary to remove the screw to place the clamp in position on the span wire and conduit.

The cover opening of the Condulet can be equipped with an Obround attachment plug receptacle which will permit the fixture to be wired with an attachment plug cap, thereby providing easy removal of the fixture for cleaning. Obround one-wire hole covers can be used instead, if removal of the fixtures is not desired.

A Nationwide Distribution Through Electrical Wholesalers

Condulet Catalog No. 2500 will be sent on request.

CROUSE-HINDS COMPANY
SYRACUSE, N. Y., U. S. A.

Sales Offices: Birmingham — Boston — Chicago — Cincinnati — Cleveland — Dallas — Detroit — Houston — Kansas City — Los Angeles — Milwaukee — Minneapolis — New York — Philadelphia — Pittsburgh — San Francisco — Seattle — St. Louis — Washington
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CROUSE-HINDS COMPANY OF CANADA, LTD., *Main Office and Plant:* TORONTO, ONT.

ASSOCIATION OF IRON AND STEEL ENGINEERS

ANNUAL SPRING CONFERENCE

MONDAY, APRIL 28, 1941

OHIO HOTEL

YOUNGSTOWN, OHIO

Program

(EASTERN STANDARD TIME)

9:30 A. M.

TECHNICAL SESSION

Chairman
J. L. MILLER, *Assistant Chief Combustion Engineer,* Republic Steel Corporation, Cleveland, Ohio.

Vice-Chairman
L. N. McDONALD, JR., *Chief Power and Fuel Engineer,* Carnegie-Illinois Steel Corporation, Youngstown, Ohio.

"Stoker Applications for Combination Firing of Boilers"
By OTTO de LORENZI, Combustion Engineering Company, Inc., New York, New York.

"Maintenance of Instruments and Control in the Steel Plant"
By A. E. KROGH, Brown Instrument Company, Philadelphia, Pennsylvania.

1:30 P. M.

INSPECTION TRIP

An inspection trip will be made through the Sharon Works of the Sharon Steel Corporation, Sharon, Pennsylvania. All guests must use the special buses which will leave the Ohio Hotel promptly at 1:30 P.M.

6:30 P. M.

DINNER

BALL ROOM, OHIO HOTEL

8:00 P. M.

TECHNICAL SESSION

Chairman
STANLEY GRAND-GIRARD, *Superintendent of Maintenance,* Sharon Steel Corporation, Sharon, Pennsylvania.

Vice-Chairman
FREEMAN H. DYKE, *Superintendent,* Blooming, Bar and Hot Strip Mills, Wheeling Steel Corporation, Steubenville, Ohio.

"Grounded Direct Current Systems for Steel Mills"
By H. A. TRAVERS and L. L. FOUNTAIN, *Power System Engineers,* Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pennsylvania.

"Operating Problems in Bar Mills"
By W. H. BENNETT, *Superintendent,* Gautier Department, Bethlehem Steel Corporation, Johnstown, Pennsylvania.

Please Make Early Reservations to:

ASSOCIATION OF IRON AND STEEL ENGINEERS

1010 EMPIRE BUILDING

PITTSBURGH, PENNSYLVANIA

ITEMS OF INTEREST

W. C. Kitto was appointed superintendent of the steel division, Pittsburgh Steel Company, Monessen, Pennsylvania. Mr. Kitto was born in Johnstown, Pennsylvania, in 1887, and in 1901 he started to work in the laboratory of the Franklin open hearth of the Cambria Steel Company. In 1905, he was made second helper in the open hearth at the age of eighteen. He subsequently worked at the Lackawanna Steel Company in Buffalo, New York; the Bethlehem Steel Company at Bethlehem, Pennsylvania; the Gulf-States Steel Company at Gadsden, Alabama; and the Colorado Fuel and Iron Company, Pueblo, Colorado.

Mr. Kitto became affiliated with the Pittsburgh Steel Company as first helper in the open hearth department in the early part of May, 1911. In 1912, he was promoted to melter foreman; in 1922 he became assistant superintendent of the open hearth department, holding this position until 1925 when he was made superintendent of the open hearth department. In March, 1940, he was appointed superintendent of the blooming mill and open hearth department, and in January of this year he was made superintendent of the steel works division.

James M. White was made assistant general works manager of Allis-Chalmers Manufacturing Company, Milwaukee, Wisconsin. Mr. White was formerly manager of the company's La Porte Works, a post he held for the past six years. During that time he worked closely with all other company plants on special jobs. He was born in River Falls, Alabama, and was graduated from Alabama Polytechnical Institute with a degree in mechanical engineering. In 1929, Mr. White joined Allis-Chalmers and entered its graduate student engineering course, serving his apprenticeship in the West Allis Works. On completing this course he worked in various departments of the shop and in the field. In 1935, he was appointed manager of the company's La Porte Works.

Thomas T. Allison, Jr., has been made assistant superintendent of blast furnaces, Woodward Iron Company, Woodward, Alabama. Mr. Allison has been in the company's blast furnace division for the past four years.

William H. Seaman has been elected president and general manager of the National Roll and Foundry Company, Avonmore, Pennsylvania. Mr. Seaman, who resigned his position as vice-president in charge of rolls for the Mesta Machine Company, West Homestead, Pennsylvania, to take his new position, has devoted his experience almost entirely to the roll business. He attended Washington and Jefferson College and the Carnegie Institute of Technology. Mr. Seaman then became affiliated with the predecessor of Pittsburgh Rolls Corporation, the Seaman-Sleeth Company, and in 1924 left the latter to become vice-president in charge of rolls for the Hubbard Steel Foundry Company in Chicago.

Six years later, Continental Roll and Steel Foundry Company was formed, taking in the Hubbard Foundry Company, among other interests in the Pittsburgh and Wheeling districts, and Mr. Seaman became vice-president of the parent company. In February, 1935, Mr. Seaman became vice-president in charge of rolls for Mesta Machine Company continuing in this position until his recent change.

William G. Theisinger has been appointed director of welding research for Lukens Steel Company, Coatesville, Pennsylvania. Dr. Theisinger, who since 1935 has been welding and metallurgical engineer, was born in Carlisle, Pennsylvania, in 1904. Upon completion of his education in the Harrisburg public schools, he joined the Harrisburg Steel Corporation where he served until 1925. At that time he became associated with the board of transportation of the city of New York, in the development of welding inspection.

WILLIAM G. THEISINGER

In 1930, Dr. Theisinger entered Harvard University, from which he was graduated in 1934 with the degree of bachelor of science. During the summer of 1934, he served the Western Pipe and Steel Company of California as consulting engineer on high amperage, automatic welding. In 1935, after completion of post-graduate work at Harvard, he received the degree of doctor of science.

G. M. Carvlin has been appointed assistant vice-president of the engineering and construction division of Koppers Company, Pittsburgh, Pennsylvania. Mr. Carvlin joined Koppers in 1925 as a member of the research department. He later entered the operating department, from where he was promoted to sales engineer in the sales department. He was graduated from the University of Illinois in 1922 with a degree in chemical engineering. Prior to his affiliation with the Koppers Company, Mr. Carvlin was with the Corn Products Refining Company of New York.

W. L. Gable was named sales manager of the engineering and construction division of Koppers Company, Pittsburgh, Pennsylvania. Mr. Gable entered the Koppers engineering department in 1916. He later was successively chief draftsman, engineer and sales engineer. He was graduated from Cornell University in 1909, with a degree in mechanical engineering, and was with the Babcock and Wilcox Company, Barberton, Ohio, prior to joining Koppers.

J. H. Parker was elected president of the Carpenter Steel Company, Reading, Pennsylvania. Mr. Parker, who has been vice-president of this company for the past 25 years, succeeds the late F. A. Bigelow. After graduating from Cornell University, Mr. Parker entered the crucible department of the Carpenter Steel Company. In 1906 he was named assistant superintendent of that department, and in 1910 became chief metallurgist. He was elected vice-president in 1916, and under his direction much of the company's research and development work on free-machining stainless steels and other modern alloy steel products was carried out.

Obituary

Earl L. Raysor, manager of steel mill sales and Pittsburgh district manager for the Shaw-Box Crane and Hoist Division of Manning, Maxwell and Moore, Inc., died March 15, in his home in Youngstown, Ohio. Mr. Raysor was born in Harrisburg, Pennsylvania, and was graduated from Virginia Polytechnic Institute. He joined the Youngstown Sheet and Tube Company's Brier Hill Works at Youngstown, Ohio, in 1913, and later was employed by the Valley Mould and Iron Company in Chicago.

For the past fifteen years, Mr. Raysor has been manager of steel mill sales for the Shaw-Box Crane and Hoist Division of Manning, Maxwell and Moore, Inc., He was an associate member of the Association of Iron and Steel Engineers.

EARL L. RAYSOR

ASSOCIATION DISTRICT ACTIVITIES

BIRMINGHAM—MARCH 24, 1941

"Rolls and Roll Design," by CLIFFORD ELMS, *Chief Engineer*, Pittsburgh Rolls Division, Blaw-Knox Company, Pittsburgh, Pennsylvania.

CHICAGO—APRIL 8, 1941

"Protective Lighting in Industrial Plants," by L. V. JAMES, General Electric Company, Cleveland, Ohio.

DETROIT—APRIL 8, 1941

"Lubrication of Anti-Friction Bearings in Rolling Mill Equipment," by S. M. WECKSTEIN, Timken Roller Bearing Company, Canton, Ohio.

PHILADELPHIA—APRIL 5, 1941

Maintenance Symposium—W. H. BURR, Lukens Steel Company, Coatesville, Pennsylvania; F. O. SCHNURE, Bethlehem Steel Company, Sparrows Point, Maryland; A. T. HALSTEAD, Bethlehem Steel Company, Sparrows Point, Maryland; F. C. SCHOEN, Midvale Company, Nicetown, Philadelphia, Pennsylvania.

PITTSBURGH—MARCH 24, 1941

Symposium—"Application and Maintenance of Steel Mill Auxiliary Bearings"—S. M. WECKSTEIN, Timken Roller Bearing Company, Canton, Ohio; H. E. MCGOFF, Hyatt Bearings Division, General Motors Sales Corporation, Pittsburgh, Pennsylvania; A. S. MURRAY, SKF Industries, Inc., Philadelphia, Pennsylvania; A. A. VAN PELT, Norma-Hoffmann Bearings Corporation, Pittsburgh, Pennsylvania.

PITTSBURGH—APRIL 24, 1941

"Special Electrical Applications in the Steel Industry," by J. D. CAMPBELL, General Electric Company, Schenectady, New York.

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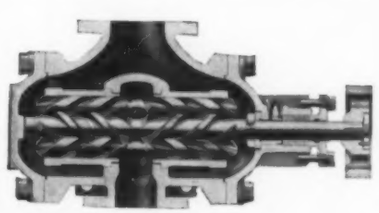
That De Laval-IMO Oil Pumps are giving satisfaction is proved by the fact that the great majority of users send us repeat orders. Our study of your fuel oil burner, hydraulic pressure, or lubricating oil pumping problem will cost you nothing, and we know that once you have used an IMO, you will become an IMO booster.



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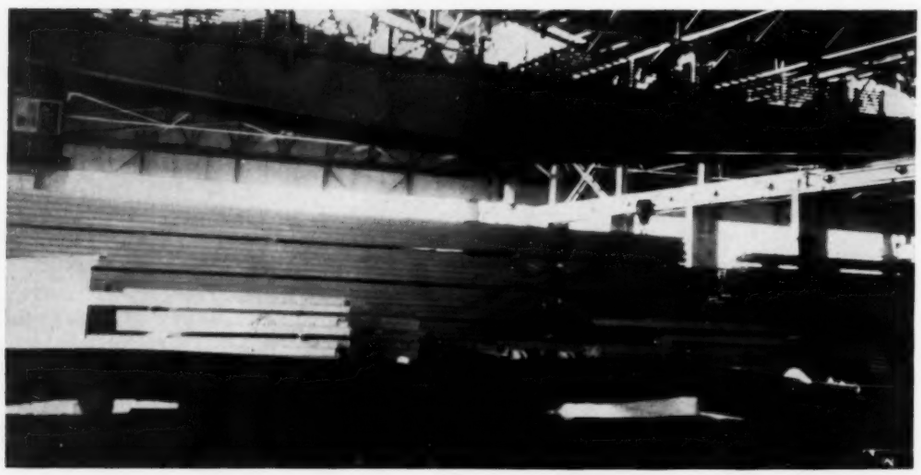
DE LAVAL STEAM TURBINE CO., TRENTON, N. J.

KEEP THEM YOUNG WITH HYATTS



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Long ago the steel industry, knowing the tough service ahead of their equipment, learned to "keep them young with Hyatts." Therefore, tables, cranes, motors, and cars were built with Hyatt Roller Bearings; and down through the years many of these earlier units and thousands since have been on the go, with no time out for bearing care. Hyatt Bearings Division, General Motors Sales Corporation, Harrison, New Jersey; Chicago, Pittsburgh, Detroit and San Francisco.

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